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Monterey, California

THESIS

NATIONAL AIRSPACE
DATA INTERCHANGE NETWORK
ANALYSIS

by

Guy M. Esten

March 1992

Co-Advisor: D.C. Boger
Co-Advisor: Bill Gates

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National Airspace Data Interchange Network
Analysis

by

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS SYSTEMS MANAGEMENT

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March 1992

ABSTRACT

This thesis is a description and analysis of the Federal Aviation Administration's National Airspace Data Interchange Network (NADIN). The objective is to define, for telecommunication students, this data interchange network and examine the effects which current network upgrades will have on network performance. Descriptions of the current Data Interchange Network (NADIN IA) and the next generation Data Interchange Network (NADIN II) are included as well as information on related FAA programs, most notably the Radio Communications Link (RCL). Analysis is presented of NADIN II's impact on the Federal Aviation Administration's Data Interchange capabilities. Implementation problems with NADIN II are addressed. Conclusions include the economic soundness of NADIN II due to leased line savings and a strong recommendation to the NADIN II program manager to aggressively pursue full project funding.

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I. INTRODUCTION

A. BACKGROUND

The Federal Aviation Administration (FAA) operates a vast system performing Air Traffic Control (ATC) functions, aviation regulatory functions, and all associated administrative activity. All these functions require telecommunications support, especially the communication intensive ATC system. These functions collectively comprise the National Airspace System (NAS). NAS data interchange needs are currently being provided by the National Airspace Data Interchange Network (NADIN IA).

The current Nadin IA will be augmented in 1992 with a parallel network called National Airspace Data Interchange Network II (Nadin II). NADIN II will provide the backbone for the Federal Aviation Administration's complex network of communications. This thesis will define the existing NADIN 1A system and the update program that is implementing NADIN II. It will then assess the impact Nadin II will have on the backbone network's capability to support the Federal Aviation Administration's (FAA) data interchange needs. When referring to the existing backbone network for data interchange the term NADIN 1A is used. NADIN II is the new network that augments, and is connected to, NADIN 1A. The general name NADIN, when

used alone, refers to both the existing network and the new network as they function in total to provide data interchange.

B. OBJECTIVES AND SCOPE

This thesis will define and describe the systems used to disseminate data throughout the FAA. NADIN 1A and NADIN II are the specific FAA programs addressed, but several other programs are described to provide an overview of the FAA's total backbone data interchange service.

This thesis will be approached from a telecommunication system manager's perspective. Technical information will be provided and discussed in order to define capabilities, but not to define the equipment in an engineering sense. Currently Nadin 1A is a message switched network. Nadin II will be a packet switched network with increased efficiency. This is expected to alleviate the overloading of the current system and handle increasing requirements for a wider variety of data sources as FAA services increase.

The thesis will focus on the NADIN backbone network that provides data interchange for a myriad of users. Descriptions of the services provided by these users is required to understand the wide variety of data transfer requirements and associated interfaces and protocols.

Some overview of the FAA environment will be required to establish a context for NADIN, but is not meant to define the FAA as a whole. Entities outside the NADIN system itself will

be discussed if they are relevant in defining and analyzing NADIN.

Research questions were answered by analyzing FAA documents describing the current and upcoming network, as well as papers and publications on relevant topics. Interviews and conversations with various contacts at the FAA in Washington DC provided information to fill in the gaps and keep perspective on the system as a whole.

C. BENEFIT OF STUDY

The FAA telecommunication system as a whole is a massive, complex, multiple layered system utilizing almost every form of communication medium. This makes it difficult to determine where one subsystem begins and ends. Adding to this difficulty is the FAA's **service** orientation to classifying their systems, which is motivated by management and funding accountability considerations. As a result there is no single document, or group of documents, that clearly describes subsystems as deeply integrated into the total system as NADIN is. An understanding of the NADIN system must be derived from a wide variety of source documents, and the pieces to connect it all are hidden deeply in the literature of other FAA systems and facilities. This thesis will provide a single document that not only fully defines the NADIN 1A and NADIN II systems but will provide a clear understanding of the context

in which NADIN operates and its role in providing FAA services.

Analysis of the combined NADIN IA and NADIN II backbone networks will assess the flexibility and capabilities of the network as future demands are put on it.

Additionally, telecommunications students will have an in-depth description of a backbone network that is in actual use to complement the theory and somewhat segmented analysis in textbooks. Many Naval Postgraduate School students are aviators and have an intimate familiarity with the Federal Aviation Administration services as customers. This background of familiarity will provide for a greater appreciation and understanding of the network analyzed in this thesis, and the thesis will provide the aviator with a greater understanding of what is involved in delivering flight following and meteorological services to the aviator. The level and method of presentation of the thesis will be motivated by the target audience described above.

D. ORGANIZATION OF STUDY

Following this introduction, Chapter II describes the aviation environment with respect to FAA services provided. This forms a foundation for understanding values placed on the various characteristics of FAA services. Chapter III addresses how FAA services require telecommunications and gives an overview of FAA telecommunications in the aggregate.

The NADIN 1A system description comprises Chapter IV, and similarly, NADIN II is covered in Chapter V. Analysis of NADIN II's impact on the FAA's ability to meet data interchange demands is presented in Chapter VI as well as a discussion of design benefits and implementation problems. Conclusions and recommendations complete the study in Chapter VII.

II. FEDERAL AVIATION ADMINISTRATION ENVIRONMENT

A. UNDERSTANDING THE ENVIRONMENT

The Federal Aviation Administration (FAA) is an extremely complex and massive federal agency. The FAA's extensive services blanket the United States and adjacent waters, as well as interface with all international routes to and from the United States. These services are available 24 hours a day, 365 days a year. The diverse nature of these continually provided services adds to the system's complexity. When one considers the minuscule margin for error associated with the field of aviation, the magnitude of the FAA's tasks is amazing.

The diversity, complexity and magnitude of the FAA's services make it difficult for those who are not experts in the aviation field to understand the environment in which the FAA operates. Even the professional aviator may only have a superficial knowledge of the FAA's functions, based only on experience as a user of FAA services. Due to the nature of the FAA, as described above, it will be most useful to provide an overview of the FAA's services, the structure used to provide those services, and the environment in which they are provided.

In examining the backbone network of the FAA communications system, it is essential that the reader have a framework in mind when the requirements put on the network are discussed. These requirements on the network are based on the services rendered and will have much more meaning if the reader has an overview of the FAA environment.

B. THE MISSION OF THE FAA

Federal management of United States airspace existed long before the Federal Aviation Act of 1958, from which the FAA statutory mandate comes. It is this federal act that delineates the FAA's mission. This mission is summarized as follows:

> To serve the nation by providing a safe, secure and efficient aviation system which contributes to national security and promotion of U.S. aviation.[Ref. 1:p. 1-0-3]

As a part of the Department of Transportation, this broad mission is further delineated by the Secretary's National Transportation Policy. This policy consists of six key themes, which are relevant to understanding FAA motivation in some of it's decisions about communications systems. They are as follows. [Ref. 1:p. 1-0-3]

- Maintain and expand the nation's transportation system.
- Foster a sound financial base for transportation.
- Keep the transportation industry strong and competitive.
- Ensure the transportation system supports public safety and national security.

- Protect the environment and the quality of life.
- Advance U.S. transportation technology and expertise.

The commitment of the Department of Transportation and the FAA goes beyond providing required services. It includes the welfare of the aviation industry in general. The FAA certainly has the means and the authority to affect the welfare of the aviation industry. This responsibility to the industry impacts many FAA decisions regarding resource allocation and most other facets of FAA policy and structure.

C. AVIATION USER GROUPS

There are three principal aviation user groups utilizing the services provided by the FAA. These include air carriers, general aviation and the military.

Air carriers (airlines) employ large, expensive jet aircraft with sophisticated avionics. Air carriers require the ability to routinely fly minimum cost operating routes while minimizing delays and retaining access to all weather services. Schedule reliability is paramount for this group and sufficient airport and flight service capacities is critical.

The general aviation group includes personal transportation, business aviation, helicopters and recreational aviation. Aircraft capabilities vary greatly in this group but the lowest common denominator is aircraft with

limited avionics, a need for flight planning assistance and accurate weather information.

Military flights often require special handling due to associated high speeds, unusual maneuvers and altitudes, and the use of special use airspace. It is appropriate to note that the military provides and operates 58 radar approach controls, 91 ground control approach facilities, and 206 control towers in support of military operations [Ref. 1:p. 1-0-9]. These facilities also provide air traffic control services to the public, which are equivalent to services provided by FAA facilities.

D. THE AVIATION ENVIRONMENT

To begin to understand the FAA's services, an overview of the aviation environment is in order. Most aviation traffic consists of flights that originate at an airfield, include an en route phase, usually at high altitude, and are completed upon arrival at another airfield. The airfields of departure and arrival vary in size and traffic density. The higher the traffic density, the more complex the air traffic control system and procedures at that terminal area. As a result, terminal characteristics vary with traffic density. Terminal characteristics include organization structure, procedures and the services provided. Departing and arriving comprises the terminal phase.

The smallest of these airports would be private fields, small municipal airports and other fields without control towers. Airfields with control towers are usually in areas of higher population density and thus in the physical proximity of other airfields. If the number of airfields in close proximity warrants, or if one terminal area has enough air traffic, an approach control is established. The approach control provides air traffic control services to this area. Even these approach controls vary in size, from a small approach control area like Pensacola, Florida, to large super-dense areas like Los Angeles or Chicago. The nomenclature for this air traffic control hierarchy is not important here, but the concept of varying usage and service levels at terminal areas is. This will become quite useful in later discussion of network topology.

These terminal areas handle air traffic control services for aircraft departing, arriving or transiting the approach area. Note that normally an en route aircraft will be at high enough altitude to fly above the approach control area, as this area is altitude limited. Once outside the approach control area, by either flying beyond its horizontal boundaries or ascending above the area, the aircraft receives air traffic control services from the air route traffic control centers (ARTCC) or, as more commonly called by aviators, the "center". These centers not only control en route traffic, but coordinate between all the approach

controls in their area and with other centers. The en route aircraft is passed from center to center until arriving at its destination approach control area. At this time, the center controlling the aircraft will pass control to the approach control.

While a flight is en route, flight-following information must be passed from one controlling entity to another in a time critical fashion. Controlling entities have prior information about the flight plan of the aircraft and expect the flight to arrive in their area prior to actually assuming control. This is quite a simplification of the process, but it shows the essentiality and timeliness of information critical to this process.

Not all flights fit the profile described above. Some flights originate at airfields not within an approach control area. Aircraft departing these outlying fields can, once airborne, contact centers, nearby flight service stations or approach controls to commence the normal flight following services. Those aircraft not going anywhere in particular, but returning to their point of departure after completion of their flight, usually fall into several categories. Private pilots may want to just fly around and usually do so at relatively low altitudes outside of approach control airspace. They usually fly under visual flight rules and only require minimal flight following advisories. Military aircraft often use normal flight following services to transit to a special

use airspace for training. Once in this special use airspace they only require limited flight advisories until returning to their home base via the normal procedures described above. These basic flight profiles are the most common, but they are not a comprehensive list.

E. FAA SERVICES

The myriad of services provided by the FAA all have a common ground. They require communications. The services discussed in this section will either require direct use of the national airspace backbone network for data interchange, known as NADIN 1A, or will indirectly impact the communications requirements of the network. Those services will be described in depth in later chapters. The purpose of this section is to provide an overview of the FAA environment as it relates to these services.

The order in which the various services will be presented in this section will model the order in which a pilot may use the services on a typical flight profile. Nontypical services may be interjected as appropriate or mentioned at the end. This format will provide a more logical reference framework and therefore enhance the understanding of these services.

1. Filing Flight Plans

Preflight planning includes checking Notices To Airmen (NOTAMS), which include listings of inoperable airfields and

equipment, active prohibited or "hot" areas, etc. A thorough weather briefing is a must. Thus world wide weather data must be available. Filing a completed flight plan is done at a flight service station (FSS) or at a Base Operations with direct access to a FSS. The FSS or base operations will also provide the NOTAMS and weather briefing service. The flight plan goes into the FAA communication system and is put in storage until "activated" by a ground control or FSS. When ready to start his engines, a pilot will communicate, via radio, to ground control and request activation of his flight plan. At this time, the flight plan data will be disseminated to the airfield tower, approach control, center, and all controlling facilities that the flight will encounter. The release of the flight plan is coordinated through the traffic management system computers, as is the progress of the entire flight. This overseeing of traffic management by a central computer system requires continual information flow from the air traffic control facilities to the traffic management computing facilities.

2. Departure and Approach Phases

While departing or arriving at an approach area or airfield, various services are provided including radar following, radio voice contact, instrument landing devices, and other navigational devices utilizing RF transmissions.

These services typically only relate to NADIN 1A with respect to passing a flight's status on to other controlling facilities.

3. En Route Phase

While en route the flight is monitored by the ARTCC. Radar contact is usually maintained when geographically possible. In addition constant voice contact is maintained via air-to-ground radio. A particular center (ARTCC) is responsible for a large geographic area. For instance, in the southeastern United States, Jacksonville (Florida) Center is adjacent to Atlanta (Georgia) Center and Houston (Texas) Center. Figure 1 depicts the locations of the ARTCCs [Ref 1]. The range of area boundaries from the actual center facility may be 200 to 400 nautical miles. Radar contact and voice contact is obviously not transmitted across ranges of this magnitude. Each center has a network of remote radars and voice radio transceivers. These remote facilities are linked to the ARTCC via a Radio Communications Link (RCL), usually microwave transmission links with facilities about 30 miles apart. This allows the ARTCC to monitor radar contact and maintain voice communication with a flight anywhere in its area. This RCL is quite relevant to the NADIN 1A system as future plans to transfer much of the NADIN 1A transmission links to microwave will utilize the existing RCL facilities or their upgraded descendants.

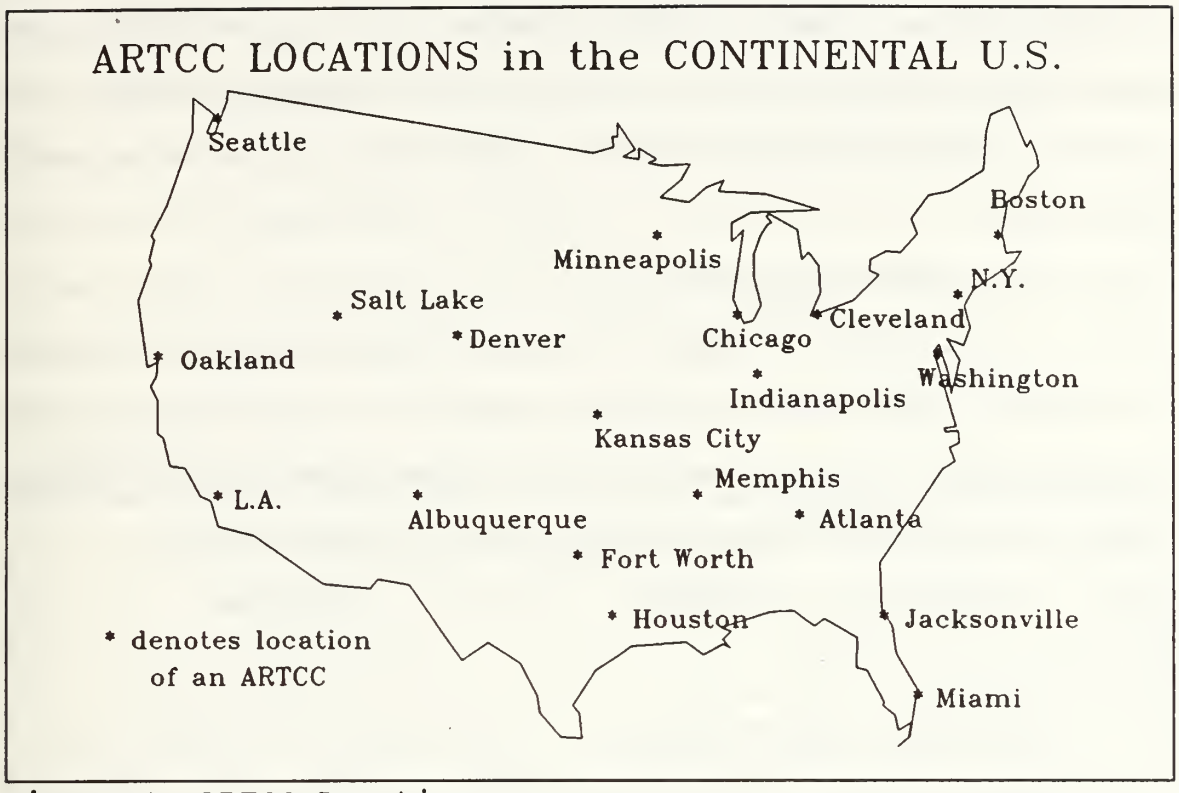

Figure 1 ARTCC Locations

4. Other Services

The menu of other services is too extensive to list here, but it includes coordination with adjacent nations' airspace systems, transoceanic flight following, and many services integral to the typical flight profiles above.

F. TELECOMMUNICATIONS FACILITIES

The number and variety of FAA telecommunications facilities is enormous. Each facility requires communications with the system as a whole. Each facility type has to communicate different information to other facilities. This diversity of facility and information types requires numerous protocols and interfaces to interconnect these facilities into

a functioning communication system. To illustrate the magnitude of this system, information is presented about the different facility types and the number of facilities in each major type.

1. En Route Facilities

There are 14 different types of en route facilities, the major types being ARTCCs, Remote Air to Ground voice Communications (RCAG), remote Air Route Surveillance Radars (ARSR) and navigational aids such as VOR and TACAN [Ref. 2:p. I-15). There are 24 ARTCCs, 686 RCAGs, 143 ARSRs, and 1025 VORs [Ref. 2:p. I-8].

2. Terminal Facilities

There are 38 types of facilities used to provide terminal services. [Ref. 2:p. I-15] Major facility types include 264 airport surveillance radars and 653 air traffic control towers [Ref. 2:p. I-8].

3. Flight Service Stations and Weather Facilities

There are 20 types of FSS and associated weather facilities [Ref. 2:p. I-15]. The major facilities types are the 152 FSSs and 62 Automated FSSs (AFSS).

4. Utility and Other Facilities

The 11 utility-type facilities include such facilities as the National Airspace Data Interchange Network (NADIN 1A) and Autovon interface facilities. Additionally, the "other" category includes 29 types of facilities including commercial

telephone company interfaces (TELCO) and many administrative facilities. None of the utility or other type facilities are considered major. [Ref. 2:p. I-15] The information in this section is summarized in Table 1 [Ref. 2:p. I-15]. All of these major facilities and most non-major facilities will require communications that directly or indirectly place demands on NADIN 1A.

Table 1. FAA FACILITIES

TELECOMMUNICATION FACILITIES								
EN ROUTE				TERMINAL		FSS/Wx		UTILITY /OTHER
14				38		20		11/29
ARSR	ARTCC	RCAG	VOR	ASR	ATCT	FSS	AFSS	NONE
143	24	686	1025	264	653	152	62	-

Figure 2 was created from information contained in Reference 1 and Reference 2 and the authors general knowledge as an aviator and shows operational communication connectivity of some of the major components of the NAS.

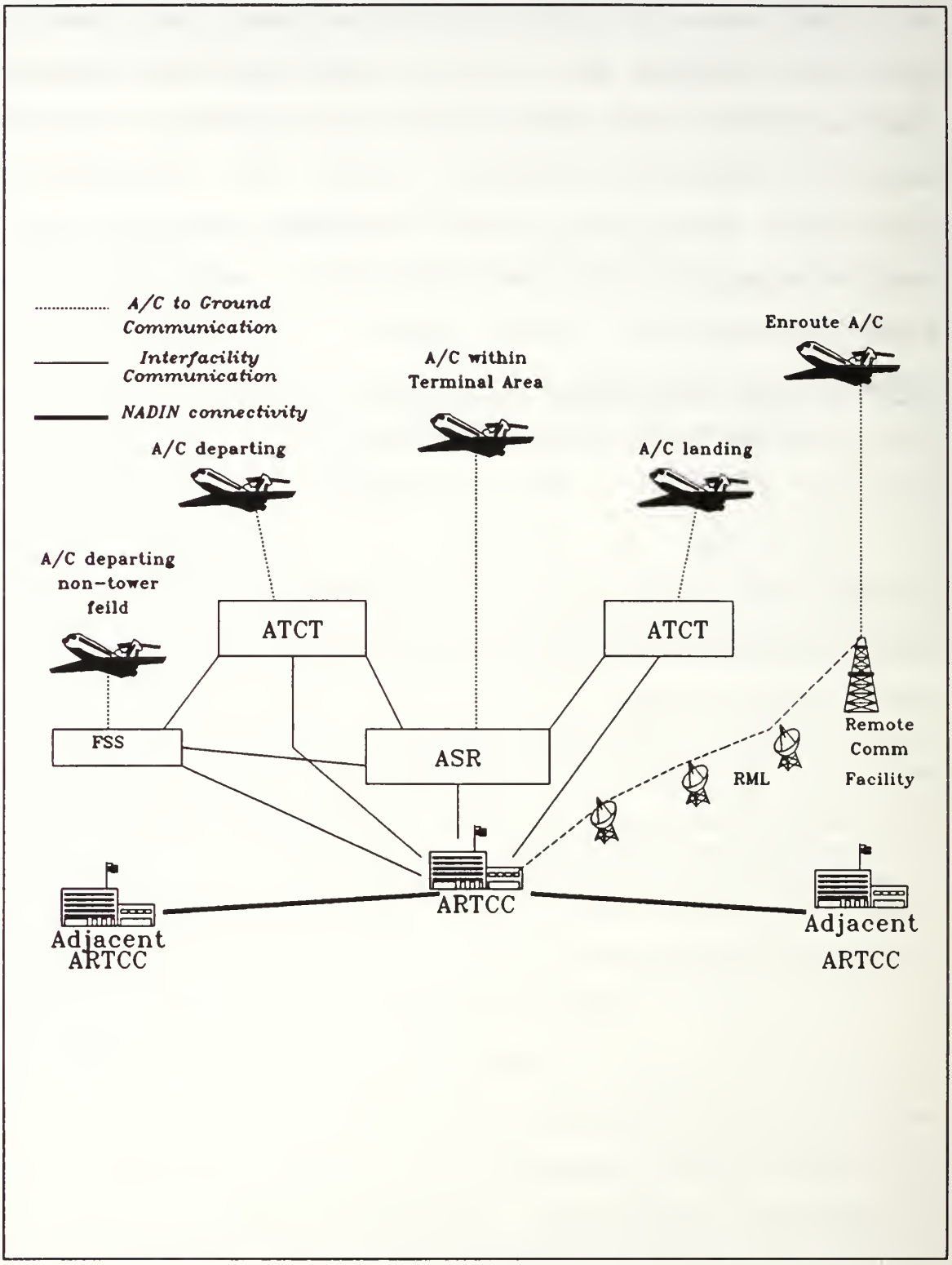

Figure 2 NAS COMMUNICATION CONNECTIVITY

III NATIONAL AIRSPACE SYSTEM TELECOMMUNICATIONS

A. THE COMMUNICATIONS SYSTEM

The services, functions and equipment described in Chapter II comprise the FAA's National Airspace System (NAS). Integral to the NAS is the telecommunications that take place between almost all of the FAA facilities. An overview of these telecommunications is provided with special attention on interfacility communication. This chapter will further discuss the backbone network of the interfacility communication system, NADIN.

There are three major components of the NAS: the Air Traffic Service System, the Interfacility Communication System and the Auxiliary System. The Air Traffic Service (ATS) system is directly involved with air traffic operations including Air Traffic Control (ATC). Air traffic control includes almost all of the aircraft-to-ground communications. The interfacility communications system supports the ATS. The auxiliary system provides administrative, maintenance and other operational support.

Air-to-ground communications always include aircraft to ground station links, and many include a link or links between an unmanned remote receiver/transmitter and manned facilities. The latter link is part of the interfacility communications

system. The ground to aircraft link is not part of the interfacility communications system, and does not interface with NADIN, although the volume of aircraft to ground communications will have some impact on NADIN because subsequent links of the associated circuit are part of the interfacility communication system. There is no particular interest in the air to ground link itself.

The interfacility links consist of commercial leased paths, microwave transmission systems, and landlines called field cable at airports and facilities. All these transmission media are relevant to NADIN.

B. INTERFACILITY TELECOMMUNICATIONS RESOURCES

The NAS telecommunications resources consist of transmission assets and equipment. The term asset is used when referring to transmission resources because the FAA leases much of its transmission capability, including over 30,000 separate accounts for leased circuits and equipment [Ref. 2:p. I-11]. These accounts are with long distance carriers and Local Exchange Companies (LECs). The FAA also owns a great deal of transmission assets and equipment, such as microwave transmission systems, field cable, modems, multiplexors, telephones, interphone equipment, Private Branch Exchange (PBX) switches, quality monitoring systems, computer driven communications processors, and hubbing devices.

1. FAA Owned Resources

The Radar Microwave Link (RML) network is owned by the FAA and is one of their most valuable resources. Currently it consists of 42 independent systems that provide broadband radar data transmissions between Air Route Surveillance Radars (ARSRs) and ARTCCs. It is comprised of 750 microwave transmission facilities. At present these 42 independent systems are being upgraded to provide state of the art microwave capabilities. These 42 RMLs will then combine with expansion segments to create a national network. This microwave network will be called the Radio Communication Link (RCL) and will provide the National Airspace Data Interchange Network update program (NADIN II) with an FAA owned backbone network transmission media. This will be discussed further in later chapters. [Ref. 1:p. 2-5-2]

Remote radar information is transferred across airport areas via FAA owned Television Microwave Links (TMLs) where it is too expensive to lay cable. Field cable or installed cable at airports and other facilities are used to connect towers, landing control systems, navigation facilities, and equipment housed in buildings. This field cable comprises the remainder of the FAA owned interfacility transmission media. Hardwired links between NADIN concentrators and equipment with which the concentrators interface are included in this field cable category. Such links might be a connection between one

computer facility at an ARTCC and another computer within the same building.

FAA owned interfacility communication equipment is significant and includes all the NADIN concentrators, switches and processors, the integrated communication switching system equipment, all the Data Multiplexing Network (DMN) equipment, and some of its telephone equipment. [Ref. 2:p. I-8]

2. Leased Resources

Leased circuits and equipment comprise the majority of the total of 2,100,000 circuit miles of FAA communications links. This represents a major portion of FAA expenditures, with the fiscal year 1990 total lease communication budget and expenditures of $262.4 million, including monthly recurring charges of $12.6 million. Figure 3 shows how those leased communication dollars were spent [Ref. 2:p. I-8,I-10].

The FAA uses the Defense Commercial Communications Office (DECCO) at Scott Air Force Base to economize in acquiring most of these commercial leases. DECCO acts as the contracting office and procures leases for the FAA in response to FAA requests for new services or modifications. Each regional Telecommunications Certification Officer (TCO) is authorized to initiate these requests by issuing a Telecommunications Service Request (TSR) via the FAA Computer Information Systems (FAACIS). FAACIS processes the TSR, retaining some data for administrative purposes and forwards

the TSR to DECCO. Some of the administrative data retained is forwarded to the National Communications System (NCS), which inventories all government telecommunication assets for use in a national emergency. The FAA is billed by DECCO, who acts as the FAA's representative to the commercial companies.

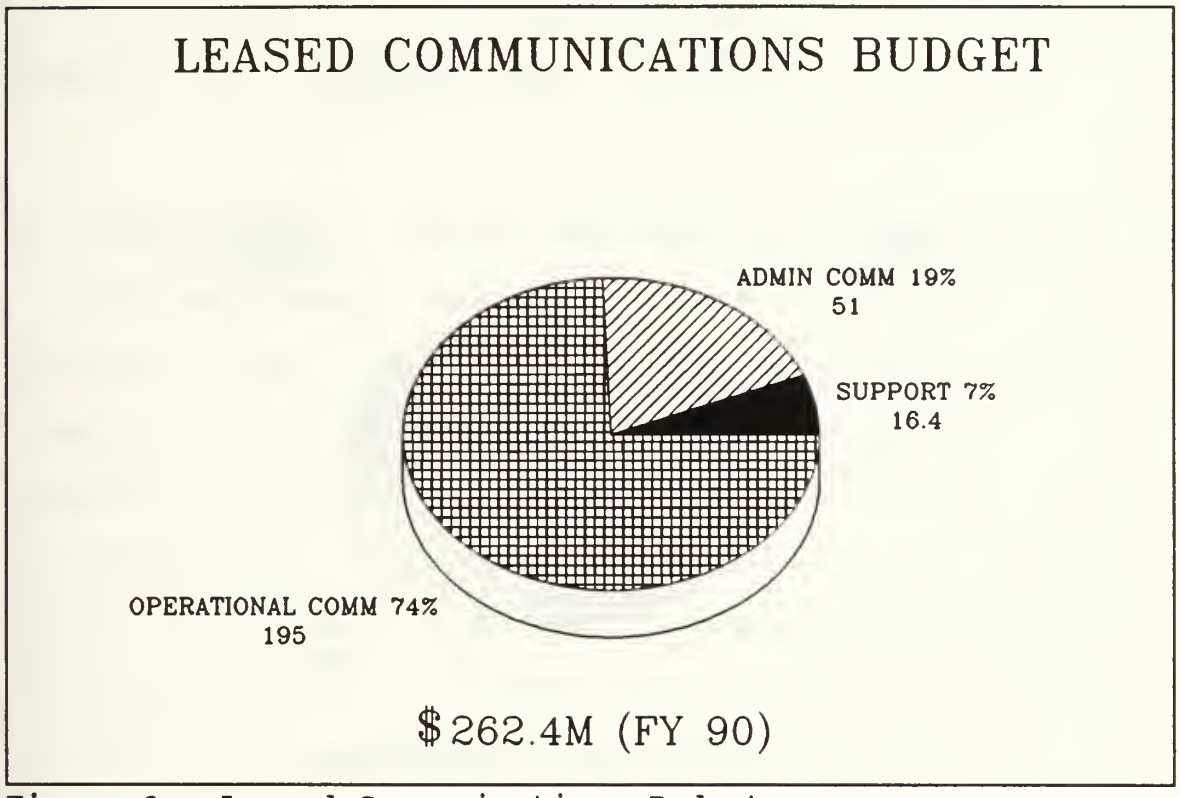

Figure 3 Leased Communications Budget

NADIN 1A links are leased assets. These assets are costly and the FAA plans to move towards FAA owned assets over time. The NADIN update (NADIN II) will utilize the RCL network to avoid the high recurring costs of leases. The economic

advantages of this approach will be discussed later. [Ref. 3:p. XI]

C. INTERFACILITY COMMUNICATIONS

Voice communications accounted for 77% of the leased asset expenditures. Data accounted for the remaining 23%. Figure 4 shows the types of communications associated with that breakdown [Ref. 3:p. I-9].

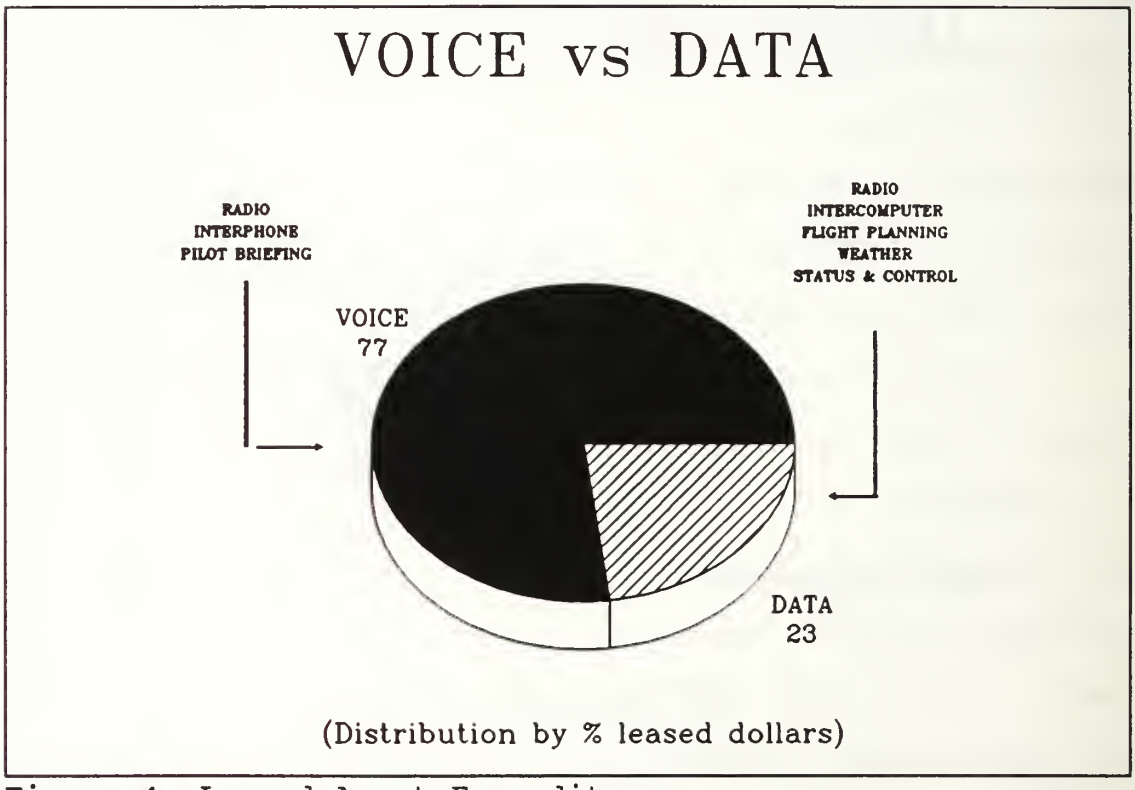

Figure 4 Leased Asset Expenditures

Figure 5 shows the percentage of the total dollars spent on circuits and equipment, segmented by environment category [Ref. 3:p. I-9].

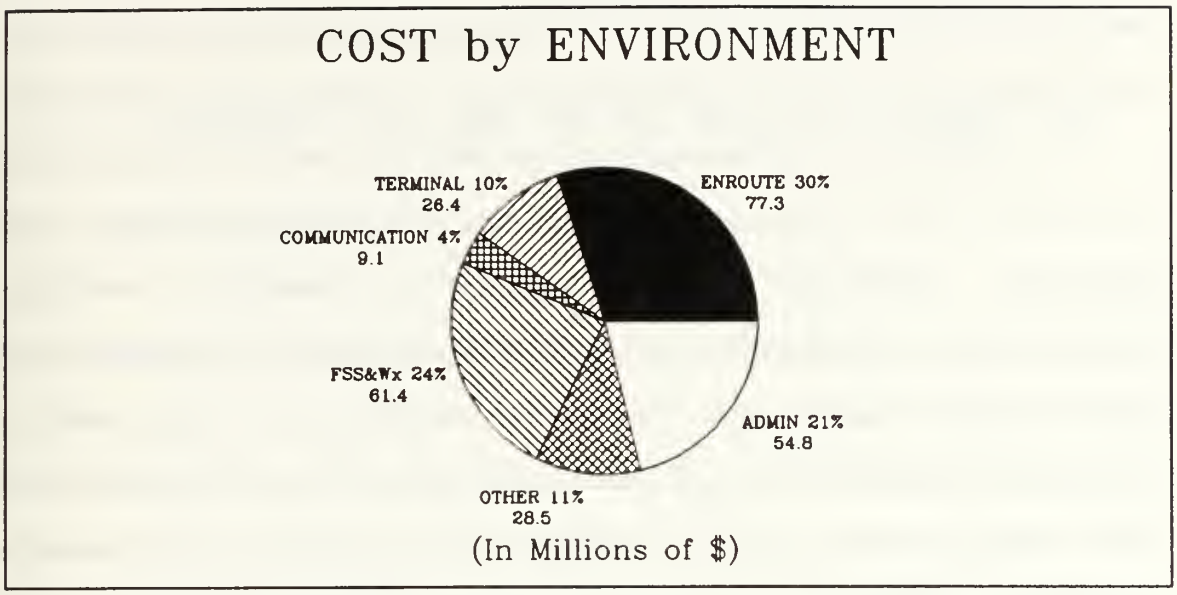

Figure 5 Cost By Environment

D. NADIN'S ROLE IN THE NAS INTERFACILITY COMMUNICATIONS

The operational system architecture of the national airspace system and the physical architecture of the interfacility communications system are congruent in many respects. The local approach controls and towers interact with other local entities and the regional ARTCC through the ARTCC. Communication between local or regional facilities and similar facilities in another ARTCC area of responsibility require ARTCC-to-ARTCC communication. This operational architecture results in the natural evolution of ARTCCs as nodes in any nationwide NAS communication network. In fact, this national level communication capability is achieved through the National Airspace Data Interchange Network. This

network utilizes the ARTCC locations as nodes and provides the backbone network for nationwide interfacility communications.

In addition to transfering air traffic control operational voice and data information through NADIN, information from national functions (e.g., weather information, NOTAMS, international connectivity, and administrative services) is disseminated throughout the nation via NADIN. Thousands of FAA facilities nationwide are operationally linked and receive the centralized source information required to provide services. Without this backbone network, the NAS would be 20 regional airspace systems with only a fraction of the services provided today. Similarly, the capability of NADIN (capacity, speed, reliability and flexibility) is one of the factors that determines the limits of interfacility communications nationwide. Thus, NADIN determines the level of service and safety the FAA can provide.

IV NATIONAL DATA INTERCHANGE NETWORK 1A (NADIN 1A)

A. SYSTEM OVERVIEW

The backbone network of the National Airspace Interfacility Communication System is NADIN IA. This network allows users to communicate with any other user on the network. This store-and-forward message-switched data network transfers flight plan data (service B information) among FSSs, ARTCCs, base operations, and international points, as well as service B traffic for Flight Service Automation System (FSAS) model 1. Weather data (service A information) and notice to airmen (NOTAMS) are some of the other major information categories using the NADIN 1A for data transfer.

1. Network topology

NADIN 1A is comprised of two star topology networks, whose center nodes are connected to create one nationwide network. Each of the 20 ARTCCs in the continental U.S. and ARTCCs in Alaska, Hawaii, and San Juan, Puerto Rico, constitute a node in the network. All nodes west of the Mississippi River are linked to the parent node of that star, Salt Lake City. All nodes east of the Mississippi River are connected to their parent, Atlanta. These two parent nodes are called NADIN 1A switches (NADSW). Each ARTCC has a NADIN concentrator (NADA) which functions as a node. Most users

will interface with a NADA. A few special users will interface directly with a NADSW via a front end processor (FEP). These special users are usually centralized information sources. Figure 6 shows the topology of the backbone network [Ref. 4:p. I-3]. Message traffic between two users must go through the associated NADA, then the NADSW where it is routed through the receiving user's NADA and to the receiver. If necessary the traffic will be routed from one NADSW to the other and then down to the user via the appropriate NADA.

There are three additional concentrators that are used for test purposes. They are linked to the switching centers like a regular node's back-up circuit, and the link capacity is limited. Two of these test concentrators are located at the FAA Academy in Oklahoma City and the other is at the FAA Test Center, Atlantic City, NJ (NAFEC).

2. Network Function

In 1988 NADIN 1A replaced several existing networks including the U.S. operated portion of the Aeronautical Fixed Telecommunications Network (AFTN) and the Automatic Data Interchange System Service B (ABDIS). It also assumed various other communication functions to become the backbone network for data interchange. It operates 24 hours per day, every day. Although it is only four years old it is scheduled to be replaced with the NADIN II update beginning in 1992. The

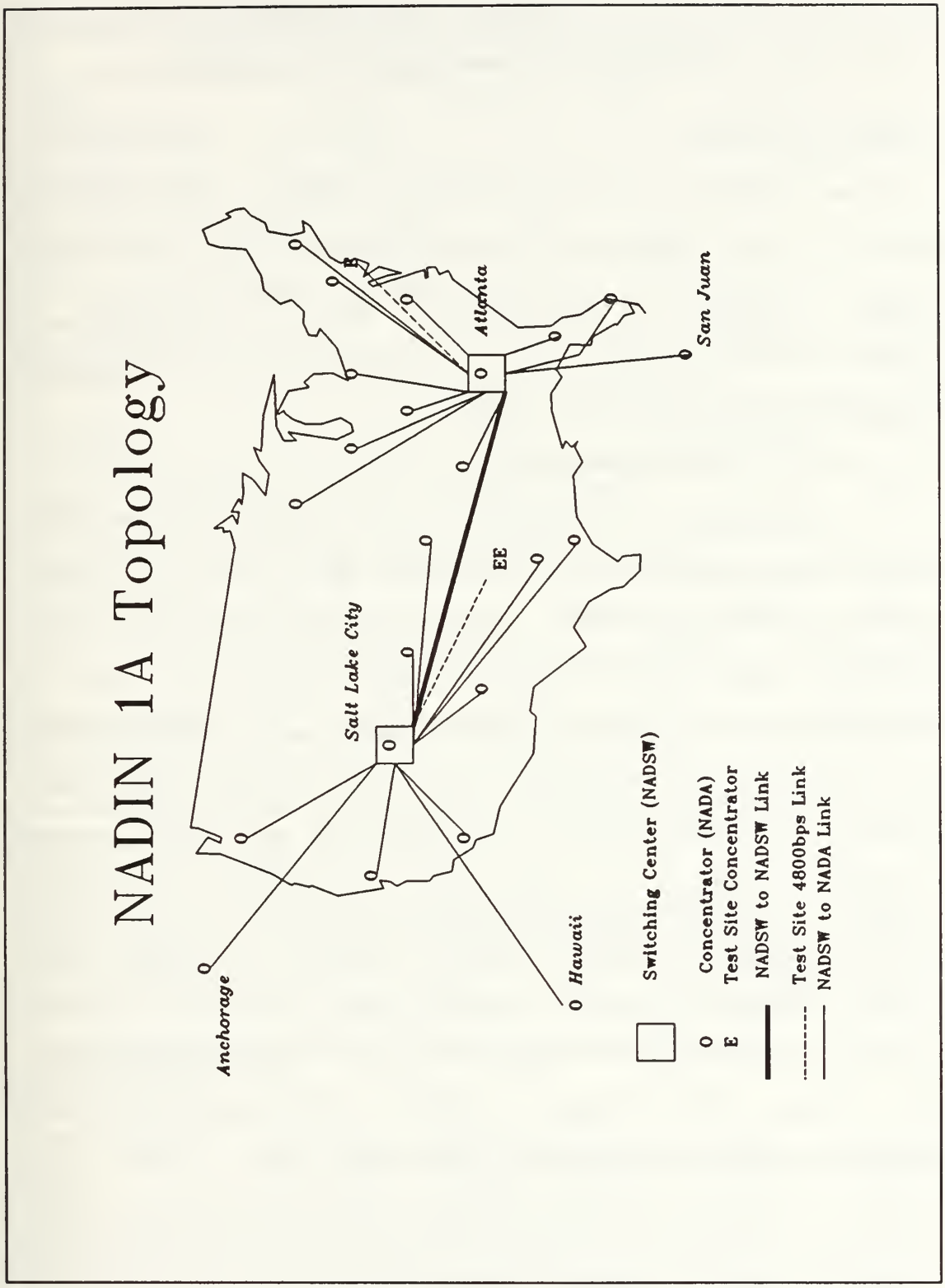

Figure 6 NADIN 1A Topology

following system description will reveal a system architecture that has been overcome by technology.

B. NADIN 1A NODES

At each ARTCC is a node of the network. The primary component of the node is a concentrator or NADA. This NADA provides users with an interface to the NADIN network. It performs protocol, speed, and code conversion functions for a wide variety of inputs and outputs.

1. User to NADA Interfaces

If a user is collocated at the ARTCC with the NADA, they will be physically linked to the NADA via field cable, or, if housed with the NADA, by some appropriate wiring. Non-collocated users have a telecommunication interface that may be an FAA asset or leased asset. These users provide their data to the NADA in a variety of protocols, speeds, and codes. Similarly, they receive data in these same protocols, speeds and codes. There are a large number of ports at the NADA to receive and send these various data formats. A single NADA may have multiple ports of a certain type. Each port type is configured to receive and send data with a specific protocol, speed, code, and format. Table 2 is a typical NADA concentrator port type listing [Ref. 5:p. 27].

TABLE 2 NADA CONCENTRATOR PORTS

NADIN CONCENTRATOR PORT REQUIREMENTS					
PORT DESCRIPTION	SPEED bps	FORMAT	CODE	PROTOCOL	OP MODE
Concentrator Switch	9600	NADIN	ASCII	HDLC	FDX
Concentrator 9020	0-40k	NAS	EBCDIC	NAS	FDX
Concentrator Dedicated Leased	1200	NADIN	ASCII	BELL 85A2	HDX
Center DTE/DARC	2400	NADIN	ASCII	X3.28/ 2.5/A-4	HDX
Remote DTE/CCC RCCC WBC	1200	NADIN	ASCII	X3.28/ 2.5/A-4	HDX
Area B	75	Serv B	Baudot	Area B	HDX
Utility B	75	AFTN	Baudot	Area B	HDX
AFTN	50/75	AFTN	Baudot	BELL 83b3	HDX
Panama AFTN	300	AFTN	ICAO-7	Cat B	FDX
MAPS/AWANS	1200	AFTN	ASCII	x3.28/2.4 /B.1	HDX
International AFTN	50/75	AFTN	Baudot	PP	FDX
FDIO	2400	NADIN	ASCII	HDLC	HDX
WMSC (weather)	2400	NADIN	ASCII	Cat B	FDX
NFDC	2400	NADIN	ASCII	Cat B	FDX
Concentrator Switch Network Backup	1200	NADIN	ASCII	HDLC	FDX
FDIO Backup	2400	NADIN	ASCII	HDLC	HDX
KWAN	1200	NADIN	ASCII	Cat B	FDX
FSDPS Model II	4800	NADIN	ASCII	HDLC	FDX
AWP Switch	9600	NADIN	ASCII	HDLC	FDX

NADIN CONCENTRATOR PORT REQUIREMENTS					
PORT DESCRIPTION	SPEED bps	FORMAT	CODE	PROTOCOL	OP MODE
Switch Auto Dial	1200	TBD	TBD	TBD	HDX
Test Concentrators	4800	NADIN	ASCII	HDLC	FDX
Spare Concentrator	1200	TBD	TBD	TBD	HDX
ARINC	2400	AFTN	ICAO-7	HDLC	FDX
Canada	2400	AFTN	ICAO-7	HDLC	FDX
Alaska	2400	NADIN	ICAO-7	Cat B	FDX
Eastern Airline Backup	2400	NADIN	ICAO-7	Cat B	FDX
Flow Control	4800	NADIN	ASCII	Cat B	FDX
Canada Dial Backup	2400	NADIN	ICAO-7	HDLC	FDX
Eastern Airline	2400	NADIN	ICAO-7	Cat B	FDX

The technical data presented in this table is provided only to demonstrate the diversity of inputs and outputs handled by a NADA concentrator.

These interface requirements are based on the user's capability to allow the user to interface with the NADIN network using his equipment. Dedicated point-to-point or multipoint circuits are required.

Modems that comply with the appropriate Federal-Standard (FED-STD) are provided on the NADIN 1A end of the circuit as a part of the NADIN system. Modems on the user end of the circuit are provided by the user. This distinction between who owns the modem is really an FAA accounting

designation and, functionally speaking, both modems at each end of the circuit are part of the network. These modems provide signaling speeds that range from 75 bps to 9600 bps, according to user compatibility. [Ref. 3:p. III-188]

2. The NADA Concentrator

The concentrator functions as a link between the various user communication lines and the backbone network. The concentrator functions are [Ref. 4:p. 1-7]:

- Time division scanning and multiplexing of incoming synchronous or asynchronous lines and the demultiplexing of information for outgoing lines.
- Assembly of the incoming serial data into characters and the detection of significant characters or character combinations.
- Serialization of outgoing characters for presentation to the lines or line modems.
- Interface with IBM 9020 equipment by converting data to/from IBM 9020 format.

The concentrator is basically a computer that is specialized to interpret all the various data inputs into a common language of protocol, speed, and codes. This common language is the IBM 9020 format.

C. THE BACKBONE NETWORK

1. NADA to NADSW Interface

Each node of the network is linked to the associated parent node of their star, the NADSW. The NADSW is housed in separate NADIN buildings at the Atlanta and Salt Lake City ARTCC locations. This parent node is comprised of three front

end processors (FEP) and two backend processors (BEP). Additionally a NADA for the parent node user area is located at the NADSW. The FEPs and BEPs function together to create a switching center. The incoming messages from various NADAs are routed to the destination NADA. The communication link between a NADA and NADSW is a leased line. Most of these links are provided over AT&T Digital Data Service (DDS) facilities. The transmission requirements are two full period, full duplex synchronous data channels at 9600 bps each. There is a reliability requirement of 99.999%. An automated dial back-up at 4800 bps for each data channel is required. This dial back-up is initiated at the switching center by operator command in the event of a dedicated link failure [Ref. 4:p. 1-8]. Dial back-up circuits are analog. When analog transmission facilities are used in lieu of AT&T DDS then D2 line conditioning is required.

Protocol requirements for these NADA to NADSW links are defined in FED-STD-1003A/FIPS publication 71, and prescribe asynchronous balanced mode with options 2 and 8 for link layer. This is considered high level data link control (HDLC) procedures. Maximum frame size is 2000 bits. The data link protocol is X3.66 ADCCP. The network layer protocol is unique to NADIN 1A.

All modems, DDS channel interface units, switching equipment, and multiplexers are FAA owned and a part of NADIN hardware. They require RS-232C electrical characteristics,

and all modems have local/remote loopback and test mode features. [Ref. 3:p. III-186]

2. Special User to NADSW Interface

Access to the network is not limited to operational users. Much of the centralized information services are provided to the users via NADIN. These include national weather information, notices to airmen (NOTAMS), international and transoceanic flight services. These users do not go through a NADA, but they access the network directly at one of the two NADSWs. The transmission requirements for this link are dedicated, full duplex circuits at 2400 to 9600 bps. Automatic dial backup is optional. Note that the very low speed data rates below 2400 bps are not available to these users. The protocol flexibility allowed to the user in interfacing with the NADA is also provided for special user access to a NADSW (see Table 2). By tapping directly into the NADSWs, nationally and internationally compiled information is disseminated to users throughout the network. Figure 7 was created, from Reference 2 information, to represent the network topology to include the end users.

3. NADSW to NADSW Connectivity

The national network is comprised of two star networks interconnected by a link from the Salt Lake City NADSW to the Atlanta NADSW (see Figure 6). The link between the NADSWs is identical to the NADA to NADSW link described in subsection 1

above. This link uses AT&T DDS service. Any message originating west of the Mississippi and destined for east of the Mississippi, or vice versa, must utilize this NADSW to NADSW link. This network topology is characterized by a 9600 bps full duplex link with a 4800 bps dial back-up that connects the two halves of the nation.

4. Test NADA to NADSW Connectivity

The test concentrators, two located at the FAA Academy in Oklahoma City and one at NAFEC, N.J., are linked to NADSWs via the dial back-up 4600 bps circuits described for NADA-to-NADSW connectivity. These test concentrators are linked by operator command in a similar fashion to initiating the NADA-to-NADSW back-up.

5. NADA to ARTCC Computer Complex Interface

The computer complex at the host ARTCC is linked to the NADA for network access. This link is via local cable, and is dual path, full duplex. Speeds up to 40 Kbps are used. Characters are transferred one at a time, bit parallel, byte serial with maximum message size at 3700 characters.

The protocol is unique to the ARTCC host computer's general purpose input/output interface adapter and is a character-by-character protocol.

D. LEASED CIRCUIT COSTS

The circuits used to link FAA users to NADAs vary in nature and the costs of those links are paid for by the FAA,

although they are not included in the NADIN backbone network costs discussed below. Non-FAA users that interface with NADIN must pay for their leased circuits that link them with NADIN.

The two NADSW to NADSW leased DDS circuits that comprise the star to star link cost $32,200 per year. The 23 NDSW-to-NADA DDS circuits cost $545,100 per year. With 99.96% DDS line availability, dial backup will be required for a total of 100 hours per year. This backup circuit cost is $48,162 per year. Note that 99.96% DDS circuit availability should not be confused with the 99.999% reliability requirement for the NADA-to-NADSW link described in section C, subsection 1. The 99.999% refers to the bit error rate associated with signal-to-noise ratios and detection error, not circuit availability. The total annual cost for leased lines for just the backbone circuits of the network is $625,462. The user-to-NADA circuit costs of the whole network would overshadow the backbone network circuit costs. [Ref. 3:p. 34-10] The relevance of these leased-circuit recurring annual costs will be evident in later analysis of the NADIN II network.

E. NADIN 1A EVALUATION

NADIN 1A network architecture evolved from a system characterized by a multitude of users with a wide variety of equipment and data. The use of concentrators at nodes of the network prevented the near impossible task of transforming all

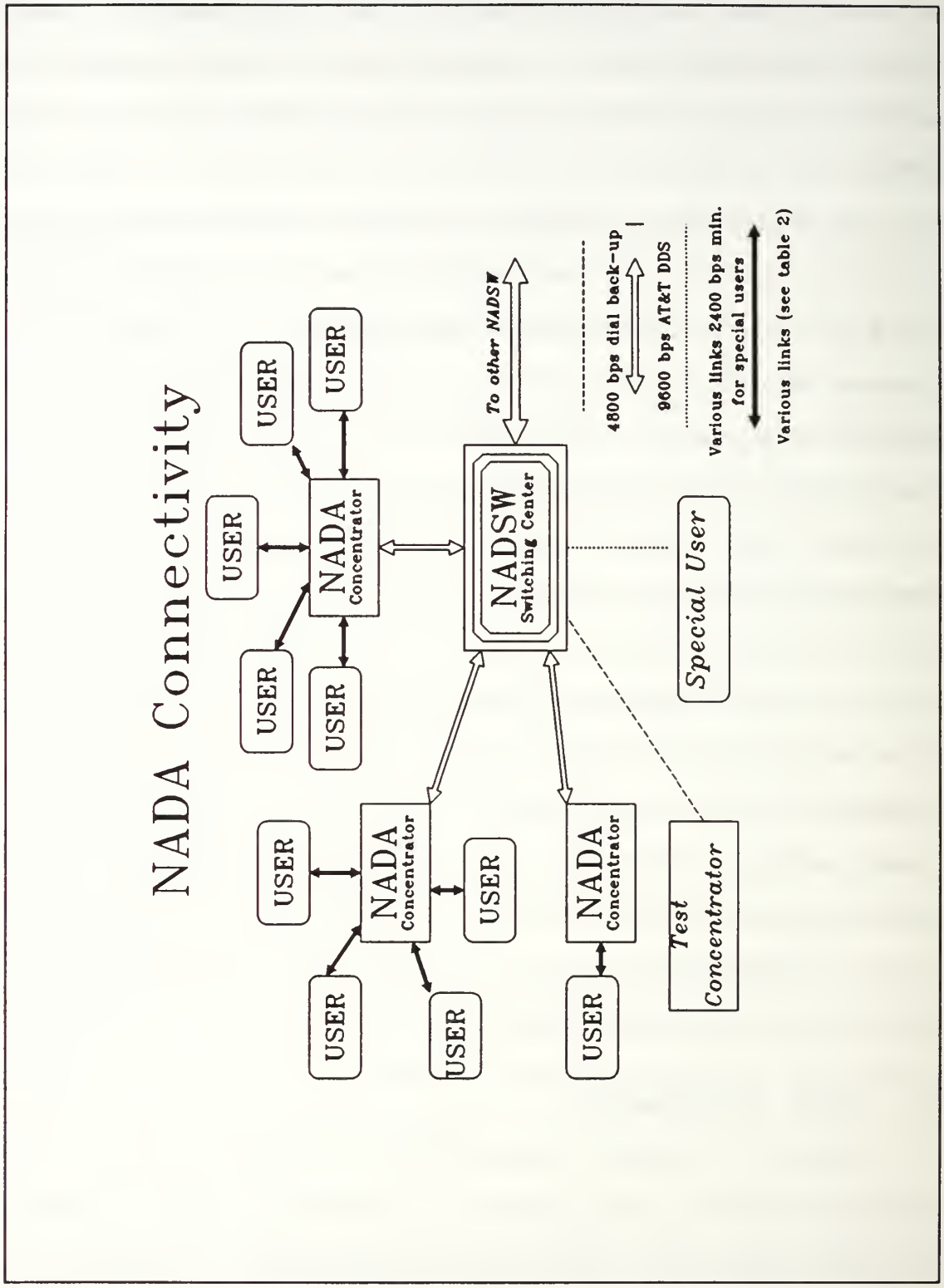

Figure 7 NADA Connectivity

users to a common interoperable data link format. The locations of the nodes naturally became the ARTCCs. To this point in the system life-cycle all the choices were good ones in light of the technology of the time and existing assets.

The topology of the backbone links of the NADIN system seems to have been less than optimum. Selecting two star topologies connected by a single 9600 bps link and a 4800 bps backup may have been motivated by the desire to centralize switching and control functions. Ring-like topologies would not have been practical and an interconnected topology would have increased leased line costs.

The increase in leased line costs associated with an interconnected topology may very well have been justified by the increased flexibility and reliability. Imagine how easily the National Airspace Communication System could be cut in half by the loss of a single circuit and its single backup. Just as easily, a single aircraft crash into a NADSW, or a fire in the NADIN building at Salt Lake City or Atlanta, could destroy the connectivity of all ARTCCs in an entire half of the nation. To a lesser degree, a power failure or equipment failure at the NADSW could halt communications. These limitations of star topologies are well known and are major motivation in the move to an interconnected topology in NADIN II.

The data rate of the backbone links seems very limited by today's standards; 9600 bps links one half of the country to

the other. As the need to carry more and more services on NADIN increases, the funneling of all eastern to western data through this 9600 bps conduit seems inadequate. This capacity limitation will be alleviated by NADIN II.

V NATIONAL AIRSPACE DATA INTERCHANGE NETWORK II (NADIN II)

A. OVERVIEW

Technology advances have allowed many additional services to be available to the aviation community. These services fulfill the needs for safety and efficiency in an increasingly congested aviation environment. The increase in demand for existing services and emerging services puts increased demands on the data interchange network.

NADIN II will satisfy the need for increased data interchange capability. NADIN II is a packet switched network (PSN) that will augment and function in parallel with the existing NADIN IA. NADIN II makes use of newer technology to greatly increase data rate capacity and employs an interconnected topology that improves reliability and flexibility. The system architecture is structured in accordance with the basic OSI reference model. CCITT X.25, 1984 version, is used at the network layer, and backbone trunks are high speed digital links. NADIN II and NADIN IA will be interconnected to allow either network access to the other.

Users of NADIN II are NADIN IA subscribers, the Weather Message Switching Center Replacement (WMSCR), next Generation Weather Radar (NEXRAD), Consolidated NOTAM System (CNS), Data

Link Processor (DLP), Automated Weather Observing System Data Acquisition System (ADAS), Flight Service Station (FSS), Remote Maintenance Monitoring System (RMMS), Traffic Management System (TMS), and Central Flow Weather Processor (CFWP). Many of these users are new services or enhanced services whose existence is predicated on the use of a high speed, robust, digital data transfer network. [Ref. 3:p. 35-1]

B. NADIN II TOPOLOGY

The network will have 24 nodes located at the 20 CONUS ARTCCs, Anchorage ARTCC, Honolulu ARTCC, and the two National Aviation Weather Processing Facilities (NAWPFS). Each node will have at least two backbone trunks, and most will have three or more. As a highly connected network, multiple routing paths between any two nodes are available and such routing will be determined by Network Control Centers (NCCs). There will be two NCCs, one in Atlanta and one in Salt Lake City. At any given time either of these NCCs will be designated the primary NCC and the other as the back-up NCC, Either NCC can perform all NCC functions. Network topology is displayed in Figure 8 [Ref. 3:p. 35-3].

1. Nodes

Each node will contain a packet switch, Protocol Converters (PCs), and Packet Assembler/Disassembler (PADs). Users that are not X.25 compatible will have access to the network via the protocol converters. The nodes will employ

multiple concentrators, requiring 100 concentrators network wide.

The nodes in Salt Lake City and Atlanta will have NCCs to monitor, control, and service the network. They will also have the gateways that allow NADIN IA and NADIN II interconnection. These are called PSN/MSN Gateways.

Additionally there will be two non-operational network support systems at the FAA Technical Center (FAATC) and at the FAA Academy for test/verification and training, respectively.

2. Internal Interfaces

The interfaces within the backbone network of NADIN II are internal interfaces. Interfaces connecting users to the network are external interfaces. Specified performance requirements state that each node should have at least two trunk connections. Figure 8 shows that this criterion has been met.

Internal interfaces will be 56/64 Kbps AT&T DDS or equivalent data channels. They will operate full duplex, and any links provided over satellite will implement modulo 128 sequence numbering to provide high link level utilization. These node-to-node links will be leased assets or links provided by the FAA-owned Radio Communication Link (RCL). The RCL is a microwave network and will be described later. The PSN/MSN gateway to NADIN IA interface is a link with the same

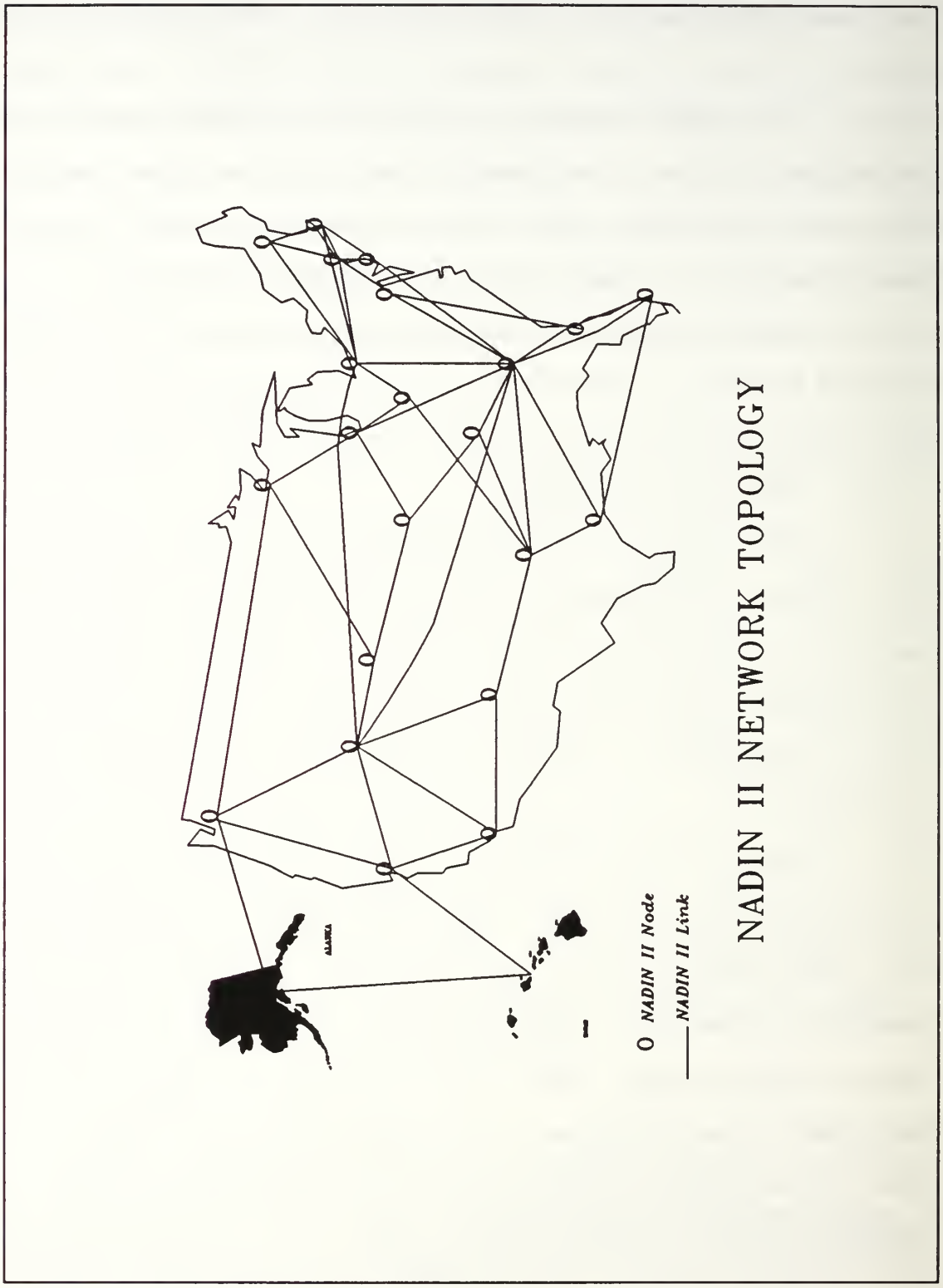

Figure 8 NADIN II Topology

requirements as the NADIN IA backbone link described in Chapter IV, Section C. This link interconnects the NADIN IA NADA with the collocated NADIN II node.

3. External Interfaces

The user-to-node external interface, typically uses X.25, but other protocols can use NADIN II protocol converters at the nodes to interface with NADIN II. The transmission requirements for each user vary but are limited to 64 Kbps. For instance, DLP to WMSCR connectivity via NADIN II requires a full period, full duplex 19.2 Kbps link, but DLP to tower connectivity requires 9600 bps link. The NADIN II node always acts as the Data Circuit-terminating Equipment (DCE) and provides the clock. The electrical characteristics are RS-232C and RS-232D. Terminations may be over local cable or modems.

4. Topology Overview

At first glance, it may seem peculiar that the FAA enhanced its data interchange network capabilities by establishing another network that augments and functions in parallel to the existing network. As with most FAA communication systems, NADIN II has evolved from specific communication requirements of unique systems, coupled with intelligent use of existing assets and upgrades made possible by technology advances. Later discussion of the Data Multiplexing Network (DMN), the RCL, and High Capacity Carriers (HCAP) will clarify the upgrade and reuse benefits in

this system. The increased demands for data interchange primarily consists of major systems, like Consolidated NOTAMS (CNS) or Remote Maintenance Monitoring System (RMMS), that will no longer have their own network but use will NADIN II. Additionally, similar centrally controlled services are emerging that are using NADIN II.

The existing NADIN IA performs the function of interfacing with a wide variety of user protocols, data rates, and formats via the NADA. The users are diverse and geographically widespread with relatively low volumes of data. This established network has well placed nodes and sufficient user to node data rates. The increase in demand on data interchange service by NADIN IA users is not significant compared to the increased demand resulting from the non-NADIN IA users described above.

Retaining NADIN IA makes good use of its interfacing capability while the parallel augmentation by NADIN II provides high data rates where most needed and the flexibility of an interconnected topology. The interconnection of the two networks permits both networks to share some of the benefits of each.

C. HIGH CAPACITY CARRIERS (HCAPS)

NADIN II backbone trunks, as mentioned earlier, will use either leased lines or the RCL. The connectivity between the node at the ARTCC and the commercial Telephone Company Central

Office (TELCO) is provided via High Capacity Carriers (HCAP). Recall that the 64 kbps channel used by NADIN II is by no means the only leased line leaving the ARTCC. NADIN IA has 9600 bps channels and many other voice and data channels exist that use leased lines emanating from the ARTCC. To preclude the use of multiple links to the TELCO, HCAPs employ T1 circuits in the following manner.

Signals are converted to digital using Pulse Code Modulation (PCM) and then multiplexed using Time Division Multiplexing (TDMUX) techniques. This multiplexed signal is carried on a T1 circuit at 1.544 Mbps. The T1 circuit used by HCAP is full a duplex, basic serial, bipolar, return to zero, synchronous digital message stream. HCAP connectivity functions are performed by FAA equipment. Use of HCAP eliminates the need for hundreds of loops between the ARTCC and the TELCO.

The FAA is currently striving for extensive use of HCAP under an FAA procurement program called Leased Interlata NAS Communications System (LINKS). LINKS will result in contracts for essentially all leased line requirements. [Ref. 2:p. III-183]

D. DATA MULTIPLEXING NETWORK (DMN)

The use of time division multiplexing is integral to the consolidation of many FAA communications. The procuring and implementation of multiplexors throughout the FAA

communication system is an FAA program in itself. The hardware combined with leased lines and the RCL comprise what the FAA calls the Data Multiplexing Network (DMN). The connectivity between multiplexing hardware is in the form of links from FAA systems already discussed, like NADIN. In the communications world the DMN would not be considered a network in itself. In typical FAA fashion, they have called a multiplexor procurement and implementation program a network. It is really only the multiplexing portion of other networks. The FAA does such program delineation for their fiscal accountability purposes and, as discussed in the thesis introduction, their documentation reflects this approach to system breakdown. The reader should not let the term "network" be confusing.

DMN equipment consists of multiplexing modems, statistical multiplexors, and associated hardware. These modems have built-in time division multiplexors that accept speeds of 2400 bps, 4800 bps, 9600 bps, and 14.4 Kbps with the latter being the most common. The statistical multiplexors combine multiple low speed asynchronous channels, each of which is transmitting only a fraction of the time, into a synchronous channel. Short term buffering and dynamic bandwidth allocation are used to achieve this.

User connectivity with the DMN modems is usually local leased lines or, if collocated, voice grade local lines are used. D1 conditioning of lines is required. Networks such as

NADIN II may accept data from modems and perform protocol and packet assembling functions, then use links such as HCAP or RCL to transmit the data to other nodes. [Ref. 2:p. III-193]

E. RADIO COMMUNICATIONS LINK (RCL)

1. Radio Microwave Link (RML)

For the last 25 years the FAA has used microwave transmissions to send radar display information from remote radar sites to the Air Traffic Control (ATC) facilities. These Radar Microwave Links (RML) consisted of microwave towers spaced 25 to 30 miles apart [Ref. 6:p. 1675] that linked remote radar facilities with Air Route Surveillance Radar (ARSR) or ARTCC facilities. A microwave tower to microwave tower link was called a hop, and all hops connecting the radar with an ATC facility comprised a system. There were many independent systems using these microwave towers and repeaters to link a specific radar to a specific ATC facility, but the links did not combine into a network.

Broadband radar service was the best the technology of the time could offer and this resulted in a single radar display signal occupying almost all of the available bandwidth for microwave transmission. Subsequent technological advances, including the Common Digitizer (CD-2), have made narrowband remoting available for both target radar displays and weather radar.

2. Network Development

The technological advances mentioned above allowed for much more efficient use of the allotted bandwidth for microwave transmission. Operating from 7.125 Ghz to 8.4 Ghz the FAA was able to stretch capacity to 960 voice frequency channels plus a T1 or broadband radar multiplexing circuit. The CD-2 enabled the transmission of remote radar to occupy only a fraction of the available bandwidth and a tremendous transmission capacity excess existed. The use of this bandwidth for other transmission needs would justify the upgrading of equipment at the microwave facilities and in fact give birth to a whole new transmission network.

The existing RML consisted of 750 microwave transmission facilities. With an additional 250 facilities the RML would be transformed into a nationwide network. This network is called the Radio Communications Link (RCL). The RML replacement and expansion program is currently underway and is upgrading all 750 RML sites with state of the art radio link equipment that utilizes digital technology. The 250 new facilities will compose 23 expansion systems that will combine with 42 existing independent RML systems to create a connected national RCL network. [Ref. 2:p. 111-193]

RCL network nodes are considered to be points of user access. The ATC facilities at the end of a segment are terminal nodes. The ARTCCs and a site in New Orleans are full terminal nodes and allow access to 960 voice frequency

channels and the T1 carrier or broadband radar multiplexing. The voice frequency channels will be Frequency Division Multiplexed (FDM). Most ARSR sites will be partial terminal nodes and allow access to 600 voice frequency channels and the T1 carrier or broadband radar multiplexing. Some RCL microwave facilities that act as repeaters will allow access to the network. Repeaters equipped with Drop and Insert Points (DIP) allow access to 600 voice frequency channels and broadband radar multiplexing. [Ref. 2:p. III-194] DIPs will be located at all non-terminal RCL sites co-located with NAS facilities, e.g. AFSS, control towers, and remote air-to-ground communications facilities. DIPs will also be located at RCL sites determined to provide least cost access via FAA owned hard-wire or leased lines. These DIPs and their access link are known as tail circuits. Reference 6 provides an interesting optimization model for DIP location analysis, but that is well beyond the scope of this thesis. RCL **backbone** network topology is relevant to NADIN II.

3. RCL Topology

The RCL backbone network topology is designed with two objectives in mind. Topology should capture present and future high capacity communications routes and maximize leased communications savings. Upgrading of existing facilities is occurring first, followed by production of new facilities. This results in network development occurring in stages.

Figure 9 shows the **physical** RCL network topology in its various stages [Ref. 2:p. III-196]. Figure 10 shows **logical** network topology [Ref. 7].

The nodes, or terminal access points, of the RCL are determined by the existence of ATC facilities requiring communications. Much of the link topology is determined by existing microwave sites, which were themselves determined by existing communication needs. Most ARTCCs had several RML systems emanating from them that terminated at surveillance radar sites. The real question is how to add the 250 new RCL sites so as to interconnect the RCL systems while optimizing topology goals. Capital costs of constructing new sites are high so careful design of placement of new facilities is critical to optimizing fiscally constrained network capability.

a. Optimizing Cost Effective RCL Topology

An infinite number of potential RCL system routes exists. The nonlinearity of such costs as leased line alternatives, terrain constraints, and regional facility costs make a mathematical model approach impractical. The FAA used a heuristic approach consisting of three steps. Using engineering judgement several hundred potential RCL topologies were hand generated using, and covered a wide range of logical and physical configurations. In this first step, site

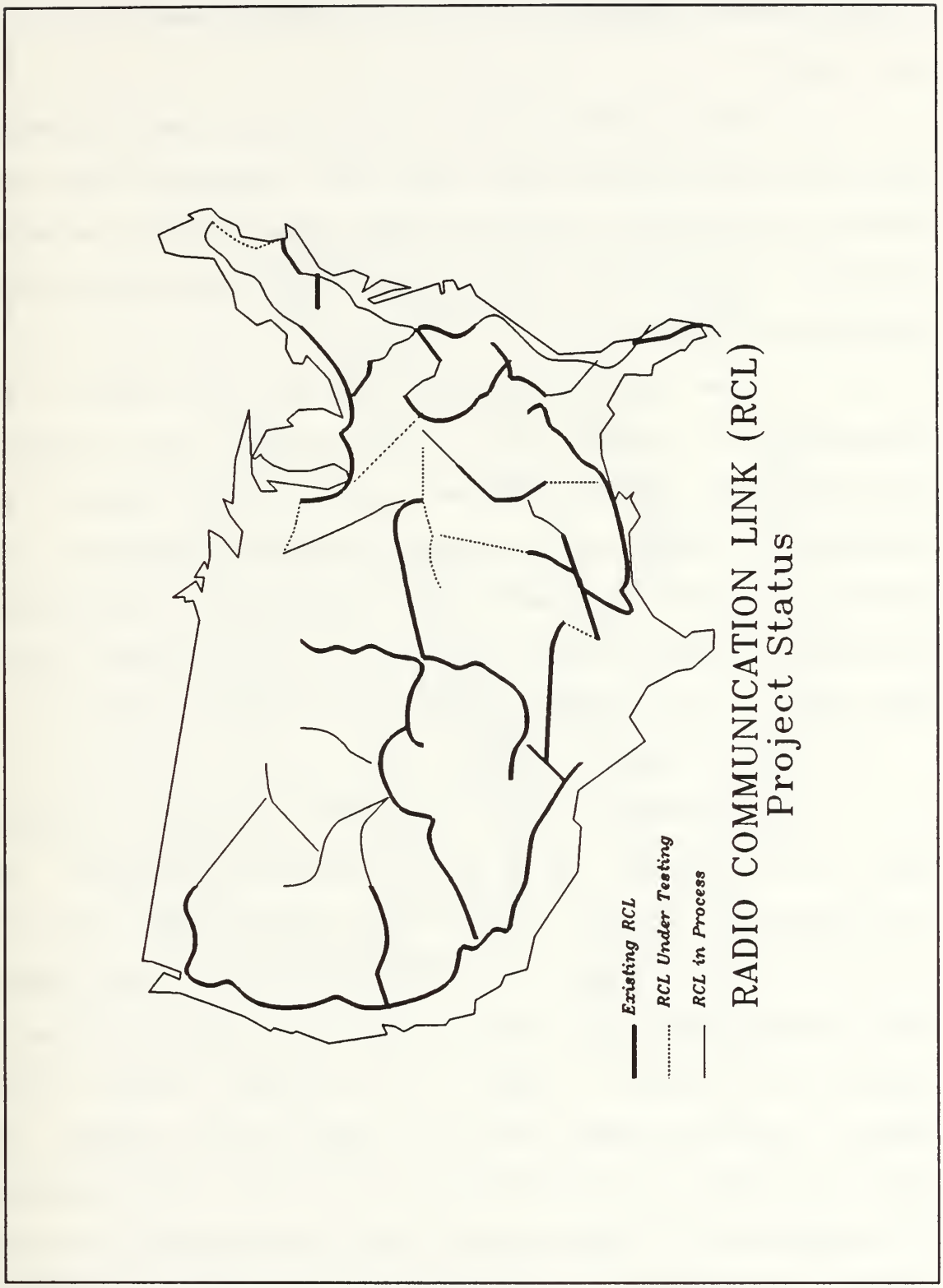

Figure 9 RCL Physical Topology

locations were determined for each topology based on 25 to 30 mile hops.

Then using a 15 year life cycle, costs including recurring and nonrecurring costs are calculated for each topology alternative. This was done using software tools and databases developed by Mitre Corporation, who conducted this analysis for the FAA.

The third step calculated the end to end communication availability. The minimum cost topology satisfying the capital cost and availability constraint was selected. Additional databases involving specific site locations were used for additional iterations of the analysis to ensure feasibility and optimality of the selected routes. The result is the topology depicted in Figures 9 and 10.

4. NADIN II's Use of RCL

The backbone connectivity between nodes of NADIN II will be via the RCL and leased lines where necessary. The development of the RCL as a national network will allow the backbone links of NADIN II to be provided by FAA-owned assets. The 64 Kbps required by NADIN II only occupies 1/24 of the T1 capacity of the RCL. NADIN II will access the RCL at the ARTCCs, which are common sites for nodes of both systems. The long range plan is to eventually use all RCL links for NADIN II connectivity. This requires use of anticipated RCL links that are not shown on Figure 9.

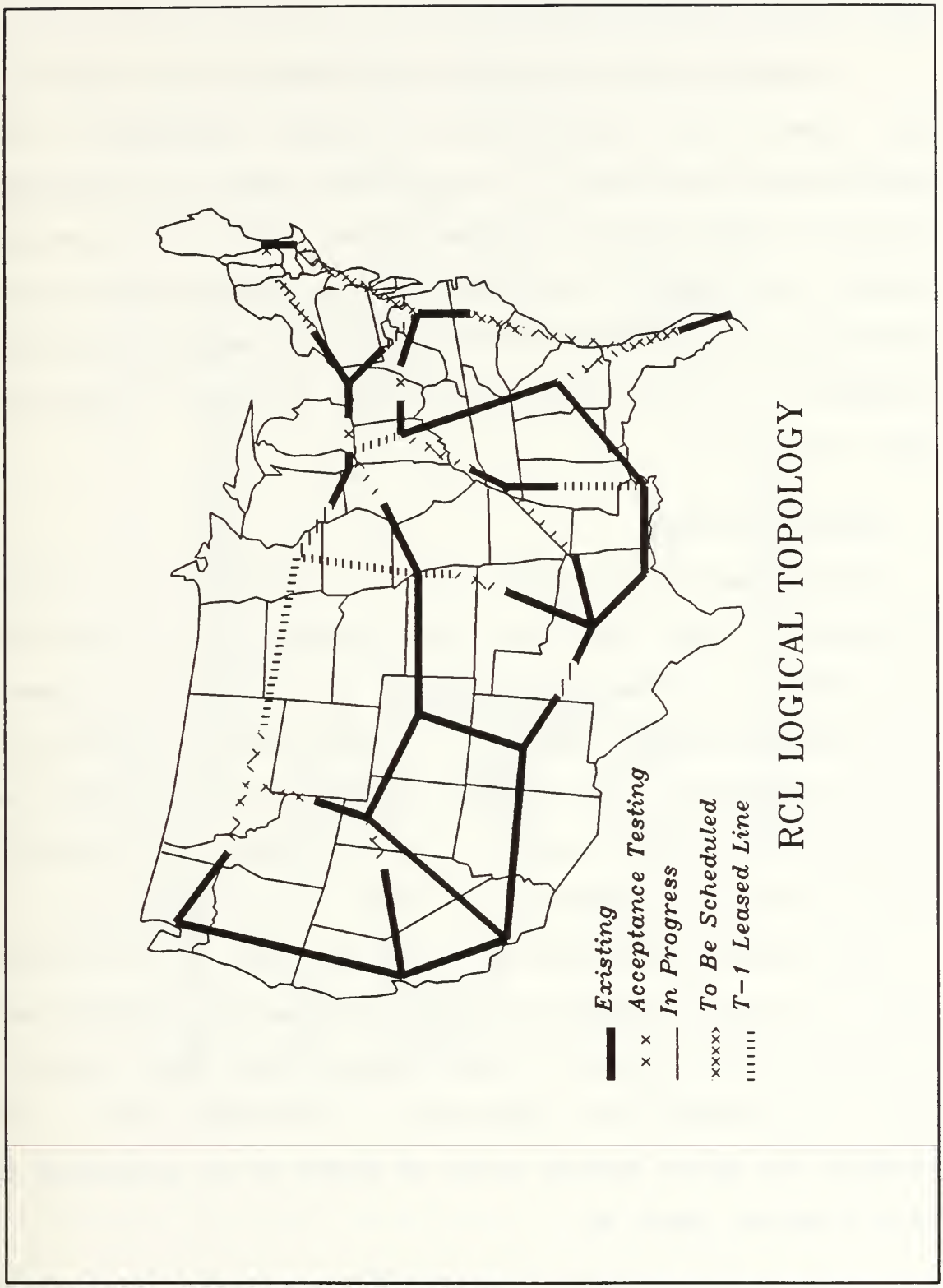

Figure 10 RCL Logical Topology

that are not shown on Figure 9.

NADIN II uses equipment and communication links that come under the jurisdiction of other programs. FAA organizational division of functionally cohesive components can obscure the overview of the system. NADIN II, as an FAA program, is separate from RCL, HCAP, and DMN, but as a telecommunications network it includes portions of these other programs. To clarify the relationship Figure 11 is provided [Ref. 3:p. 35-1].

F. NADIN II STATUS

Implementation of NADIN II is scheduled in three increments. Phase 1, part 1, is the development of a six node pilot network. Phase 1, part 2, is full network deployment and implementation. Phase 2 is expansion of operational network throughput. The system described in this chapter is completed with Phase 1, parts 1 and 2. Phase 2 is the FAA's plan to continue to upgrade interfacility communications.

The current FAA schedule is to have the pilot network (phase 1, part 1) complete by July 1992, with testing and evaluation (FAA shakedown) complete by October 1992. Phase 1, part 2 is planned for completion in December 1992. The schedule for major system users of NADIN II is presented in Table 3 below. [Ref. 8]

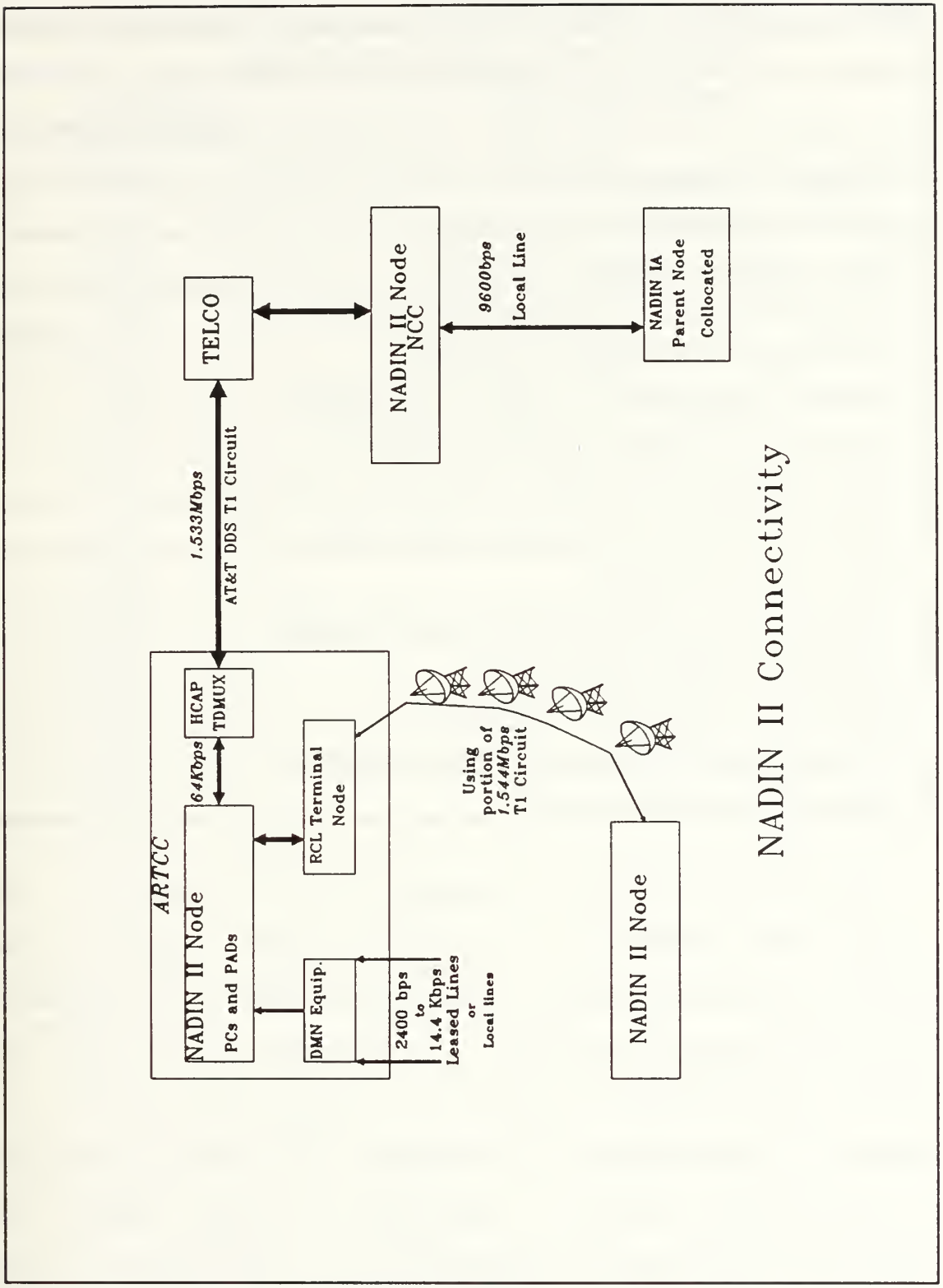

Figure 11 NADIN II Connectivity

Table 3 NADIN II USER SCHEDULE

NADIN II USER ACCESS TIME TABLE	
NADIN PSN USERS	EXPECTED ACCESS DATE
NADIN II Message Network	1993
Traffic Management Processor	1994
Area Control Computer Complex	1998
Flight Service Data Processing System	TBD
Maintenance Processor Subsystem	1995
Network Management & Control Equipment	TBD
Direct User Access Terminal Service	1994
Other Systems: Military, Airlines, etc.	1993
Weather Message Switching Center Repl.	1993
Data Link Processor	1993
Central Flow Meteorologist Wx Processor	1994
Real-Time Weather Processor	1995
AWOS Data Acquisition System	1993
National Severe Storm Forecast System	1993
Consolidated NOTAM System	1993

The NADIN II Project is supported by FAA personnel. The project team consists of a project manager, deputy project manager, business manager, contracting officer, two engineers, and two systems technicians. The support of the FAA test facility near Atlantic City, N.J., is employed as well. The program is implemented via a contract with Harris Corporation of Melbourne, Florida. Additional contract support was provided in the initial engineering of the system by other entities, most notably Mitre Corporation. The contract

vehicle with Harris Corporation is phased, meaning that final contract agreement is dependent on the successful implementation of the previous step, and it is a firm fixed price contract. A firm fixed price contract is a reasonable contract type as no technological ground breaking is being done, and all components are commercial off the shelf (COTS) items.

VI ANALYSIS

A. NADIN SYSTEM OBJECTIVES

1. Overview

Analysis of the NADIN system should begin by specifying the objectives of the system. Communications are the primary means by which the FAA provides most of its services. The backbone of those communications is the NADIN interfacility communication network. The capabilities of NADIN will directly limit the performance level of FAA service delivery. Therefore, the broad objectives of the FAA become the ultimate objectives for the NADIN system.

Safety and efficiency in the aviation environment are the results indicative of the FAA's success. These results are the means by which the FAA achieves its objectives. Recall from Chapter II, section B, the FAA policies emphasize FAA commitment to fostering a sound base for the aviation industry. The ability of the FAA to provide the services described in Chapter II is what allows the aviation industry to operate safely and efficiently at its current pace.

Failure to provide flight services at adequate levels greatly reduces efficiency. Usually safety will not suffer because FAA policy mandates procedural changes in the event of service degradation or failure. These procedural changes

ensure a continued high level of safety at the direct expense of efficiency. This trade off was demonstrated in the fall of 1991 when the physical failure of field cable at JFK airport in New York resulted in flight delays throughout the United States. As procedures that ensured safety during this failure were employed, flights into and out of New York were severely delayed. The resulting domino effect upset the efficiency of major air carriers throughout the nation.

The welfare of the aviation industry is a central concern for the FAA. Today's major air carriers are operating on very thin margins. For every successful carrier like Delta and Northwestern, there is one that has failed and one that is teetering on the brink of failure. Operating costs are a major portion of the expenditures of major air carriers, and these costs are directly affected by the quality of FAA services. The FAA has little control over industry problems, like poorly managed capital investment in aircraft procurement, but the FAA does impact such things as flight delays and efficient direct routing availability, which affect operating costs. Any negative impact on these volatile operating costs can destroy the small profit margins that exist or increase the losses currently being incurred. The relatively elastic consumer response to airline prices increases industry dependency on consistently efficient delivery of FAA services.

2. NAS Communications Objectives

The NAS communication system's primary objective is reliable and flexible communications that ensure the ability to maintain service levels that satisfy FAA goals. This requires link capacities capable of handling expected future loads, rerouting capabilities that provide satisfactory system reliability, and interoperability with current and future systems.

The capacities required of communication links must consider several factors. Future aviation use of the ATC system will impact the loads placed on telecommunication systems. The impact of new systems or services is a major consideration as many new systems are just around the corner in aviation, including worldwide navigational systems, real time weather information systems and others. Chapter V lists many of these in Table 3.

Technological advances have provided network capabilities that redefine standards for reliability, based on the rerouting capability of the new topologies available. No longer must a node in a network be dependent on a single link for connectivity. It is paramount that the FAA take full advantage of this technology as it emerges from the technology of 20 years ago.

In today's environment of rapidly changing technology, interoperability is a cornerstone of a good system. Modular design and adherence to industry protocol standards results in

flexibility when new systems require compatibility with existing systems. This is especially applicable to the FAA with many emerging systems on the horizon.

3. NADIN Objectives

As the backbone of NAS telecommunications, NADIN objectives are congruent with those described in the preceding subsection. The NADIN II project consolidates several NAS telecommunication systems and will assume the functions of more in the future. This makes interoperability a primary objective. Ensuring adequate capacities for existing and future services is also a critical objective for the NADIN systems of the future.

In times of increasing fiscal constraints achieving these objectives at minimal cost is essential. Maximizing the efficient use of technology to reach an optimum tradeoff between cost and capability is an objective which reality forces upon the FAA.

B. FAA WORKLOAD FORECASTS

Demands on NAS telecommunications will vary with two major components. New systems and services will increase this demand and increases in aviation activity will impact FAA workload requirements as well. The FAA has done extensive work in the area of forecasting activity and summarizes these efforts in the following statement.

> The FAA forecasting process is a continuous one which involves FAA Forecast Branch's interaction with various FAA Offices and Services, other government agencies, and aviation industry groups, including individual discussions with most major carriers and manufacturers. In addition, the process uses various economic and aviation data bases, the outputs of several econometric models and equations, and other analytical techniques. [Ref. 9:p. 7]

Domestic air carrier passenger miles are expected to increase 4.1 percent per year between 1990 and 2002. Emplanements, or number of passengers, are expected to increase 3.8 percent annually during the same period. The difference between these two figures is due to longer average passenger trip lengths. This increase is forecast to result in 2.4 percent annual increase in domestic air carrier operations which will directly impact demand on communications. [Ref. 9:p. 7]

International air carrier passengers miles are forecast to increase 6.4 percent annually with emplanements rising 5.9 percent annually. This high international growth rate is due to strong projected growth rates in Pacific Rim Markets. [Ref. 9:p. 8]

Regional and commuter airline activity will boom during the 1990 to 2002 period. Emplanements for 1991 were 39.7 million and are forecast to rise to 78.6 million by 2002.

Military flights are forecast to remain constant throughout the period [Ref. 9:p. 9], but this forecast was published in February 1991 and was prepared in 1990. In all probability, the recent events concerning the United States

military drawdown will result in a decrease in military aviation activity. Military aviation is not an appreciable portion of FAA activity, and any slight decrease in military aviation activity will not significantly impact FAA forecasts.

The increases forecast for aviation activity will directly affect the workload of all FAA systems and services. This consequently will increase demand on NAS telecommunications and more specifically on NADIN. Table 4 displays FAA forecasts of workload measures for the 1991-2002 time period. [Ref. 9:p. 9] Aviation activity is expected to grow at about the same rate as the general economy [Ref. 9:p. 10]. Exact numerical quantification of the impact of aviation activity increases on NADIN would be nearly impossible. The approach taken here is to use these forecasts of aviation activity to gain a reasonable expectation of future demands on NADIN.

C. DEMAND ON NADIN

1. Aviation Industry Growth

The FAA mission requires that FAA policy be constructed to ensure the health of the aviation industry. To accomplish this, the FAA must not restrict growth of the aviation industry due to lack of available services. Free market forces of consumer demand, capital investment factors, etc. should determine growth of the industry. The FAA is

Table 4 FAA WORKLOAD MEASURES

FAA WORKLOAD MEASURES			
WORKLOAD MEASURES (in millions)	1991 FORECAST	2002 FORECAST	% AVERAGE ANNUAL GROWTH
AIRCRAFT OPERATIONS	64.6	81.4	2.0
Air Carrier	19.0	17.1	0.4
Air Taxi Commuter	9.8	12.8	0.0
General Aviation	39.4	48.2	0.0
Military	2.8	2.8	0.0
INSTRUMENT OPERATIONS	47.8	61.4	2.3
Air Carrier	14.3	12.0	0.4
Air Taxi Commuter	9.8	13.4	0.0
General Aviation	19.3	25.0	0.4
Military	4.4	4.4	0.0
IFR AIRCRAFT HANDLED	38.5	48.9	2.2
Air Carrier	19.0	24.9	2.5
Air Taxi Commuter	5.9	8.3	3.3
General Aviation	8.1	10.2	0.0
Military	5.5	5.5	0.0
FLIGHT SERVICES	42.3	45.8	0.5
Pilot Briefs	11.4	12.0	0.4
Flight Plans	8.1	7.9	1.0
Aircreaft Contacted	5.9	6.0	0.0
Figures in the four bolded major categories are totals.			

committed to providing services to the industry commensurate with their needs.

A free market economy will provide a service until the marginal cost of providing that the service equals the maximum price consumers are willing to pay for that quantity, or where the marginal cost curve intersects the demand curve. This model is not applicable in this case because users of FAA services do not pay for these services directly. Since the FAA's goal is to provides all the services demanded by the aviation users, and other free market constraints determine those demands, the FAA merely determines or forecasts user demand and attempts to meet it. This is not economically efficient, but reflects the FAA's goal of not limiting aviation industry growth with insufficient services. Another justification for this approach is the enormous value placed on safety. The catastrophic nature of safety failures in aviation drives the value of safety very high. This value is not infinite but but is large enough to push marginal cost/benefit analysis toward an extreme.

Federal funds pay for FAA services, not the users of those services. The price of an airline ticket does not reflect the value of the FAA services used by the associated flight. Similarly the private pilot does not pay for the FAA services he enjoys. The cost of these benefits is assumed by the population in general, as the FAA is a public service. The FAA has attempted to place dollar values on benefits derived from all its upgrade programs nationwide. Compiling all benefits derived from upgrades requiring capital

investment, including NADIN II and RCL, between 1990 and 2025 the benefits will total 204 billion dollars. Figure 12 [Ref. 1:p. 1-0-10] shows how these benefits are divided as a percentage of the total 204 billion dollars, in constant 1990 dollars. Direct aircraft operating costs represents 35.3% of the total. A more nebulous category, passenger value of time, leads all categories with 46.0% of the total. These benefits do not reflect the costs of providing the service so they are total benefit estimates, not net benefit estimates.

Demand on existing NADIN services due to demand on FAA services by aviation users will be determined by aviation industry growth. Advances in technology have provided aviation with new service capabilities, such as global navigation systems and weather information upgrades. The nature of our society is to expect the use of these new technologies. Today's level of service will not meet tomorrow's expectations. Technological advances will increase the types of services expected by the aviation industry, and this will equate to increased demand on NADIN via new services.

2. Internal FAA Demands on NADIN

As the backbone network for NAS telecommunications, NADIN is relied upon by a variety of users within the FAA. As discussed in earlier chapters, many existing and new systems plan to use NADIN in the near future. This demand on NADIN is

the most significant factor in planning NADIN system capabilities.

With any communications network, the more users associated with the network, the more desirable participation in the network becomes. The trend in the FAA's use of NADIN is right along these lines. The consolidation of various FAA telecommunication systems to utilize NADIN is a manifestation of this principle. This reinforces the importance of interoperability achieved through adherence to industry protocol standards, so as to allow compatibility with new demand for network access.

Optimizing the number of users, N, of a network and the quantity of service provided, Q, is not a simplistic model for NADIN. N is comprised of the various FAA users of NADIN and total Q is the sum of the Qs of N users. Each of the N user will have network demands determined by aviation industry demands. The FAA also finds it extremely cost effective to allow as many network users, ie, as large an N as possible. This leaves only to forecast these internal and external demands and to ensure that network capacity is sufficient.

D. NADIN II DESIGN BENEFITS

NADIN 1A by itself was a 9600 bps network that utilized two star topologies, connected by a single 9600 bps link. This network topology is obsolete as is the data rate associated with the network. Connectivity to a variety of

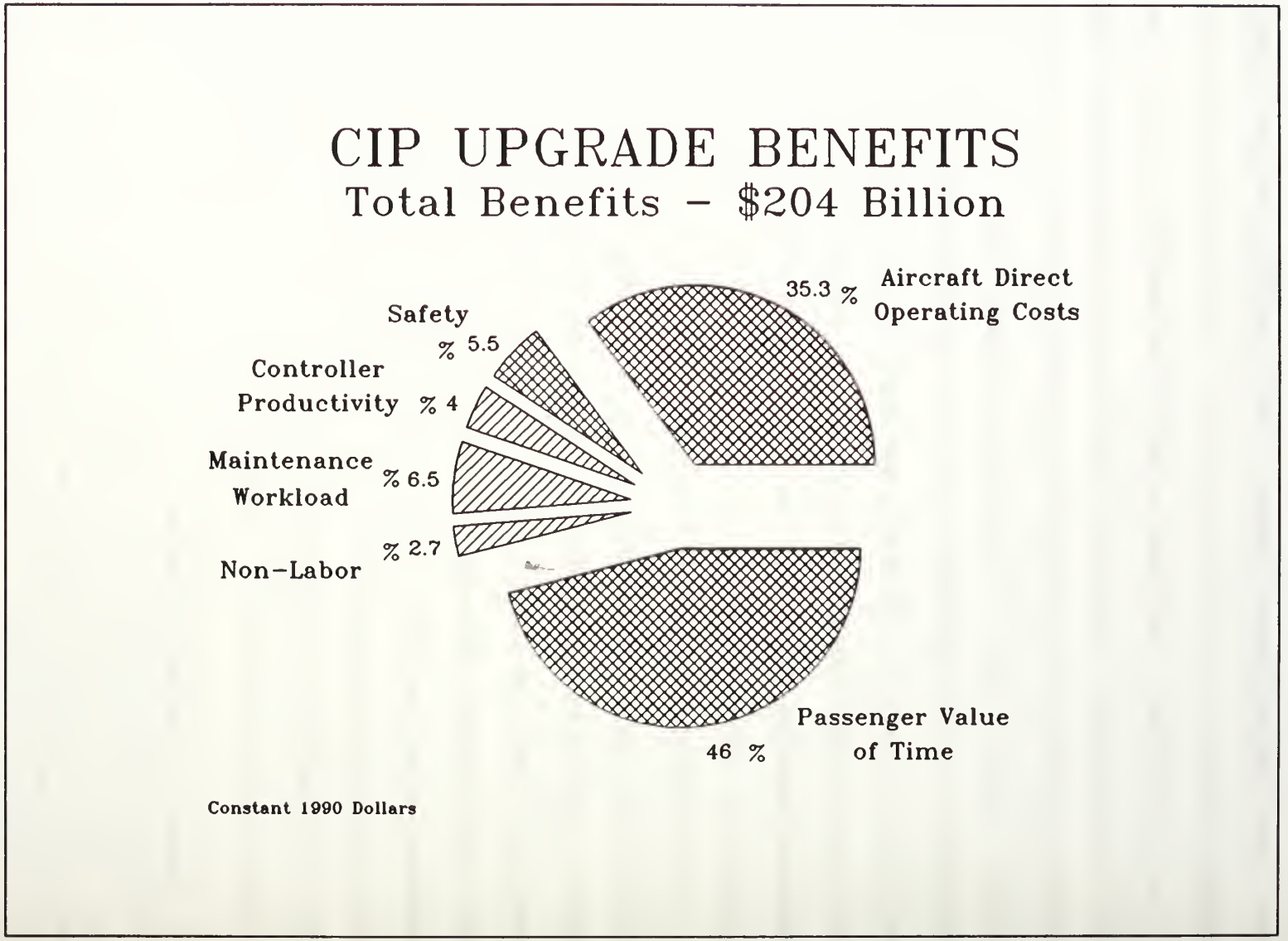
CIP UPGRADE BENEFITS
Total Benefits – $204 Billion
35.3 % Aircraft Direct Operating Costs
Safety % 5.5
Controller Productivity % 4
Maintenance Workload % 6.5
Non-Labor % 2.7
46 % Passenger Value of Time
Constant 1990 Dollars

Figure 12 CIP Upgrade Benefits

users, provided by the NADA concentrato,r was quite useful considering the multitude of users and the diversity of their existing equipment.

NADIN IA had done the job during its time but increased needs for telecommunications and rapid communication technology advances make it appear that NADIN IA is obsolete.

Improvement of the NAS telecommunication system backbone network was the task at hand. The availability of T1 circuits via AT&T DDS circuits, digital multiplexing technology, interconnected network topologies, and established industry standards for compatibility made network upgrading very appealing to the FAA. The degree to which the FAA should upgrade NADIN capabilities was almost predetermined by technology. Data networks had sprung up throughout our society, and telecommunications had taken a quantum leap forward since the design of NADIN IA. Any modernization of NADIN would provide a similar leap in capability.

Use of the Open Systems Connection (OSI) model would ensure compatibility with new users and various means of transmission [Ref 10:p. 1609]. The network layer of the OSI model provides the physical and data link layers with independence from data transmission and switching technologies used to connect systems and is responsible for establishing, maintaining, and terminating connections. [Ref. 11:p. 448] The obvious choice for the FAA data interchange network was a

packet switched network utilizing the X.25 protocol standard for the network layer of the OSI model. The X.25 standard is the best known and most widely used protocol [Ref. 11:p. 475] making it ideal for NADIN's compatibility requirements.

The number and location of network nodes were virtually predetermined by the location of ARTCCs and collocation of NADIN IA nodes. The connectivity between these nodes was determined via the methods described in Chapter V. Throughout the design of the NADIN upgrade (NADIN II) the principle of using existing systems and assets was employed. This is very apparent in two major areas of NADIN II design. These are use of the RCL and the paralleling of NADIN IA. The use of RCL links for NADIN II to avoid leased line costs was an excellent means of distributing the cost of upgrading decaying microwave link capacities. Technological advances made the RCL program compatible for NADIN II network utilization, and this was an opportunity the FAA could not have passed up. The FAA said it well in its Capital Investment Plan.

> It is highly cost effective to convert existing special purpose links used for radar remoting to general-purpose links used for interfacility communications. [Ref. 1:p. 2-5-2]

The paralleling of NADIN IA had several advantages. The implementation of NADIN II in stages will result in gradual employment of NADIN II, accessed by collocated NADIN IA nodes. NADIN IA provides a backup for existing NADIN II links until network completion makes available all rerouting capabilities

of the network. NADIN IA will provide access to NADIN II for all NADIN IA users via the NADIN IA concentrators and gateways to NADIN II. In fact, future advances in NADIN II that may assume all NADIN IA functions completely, will use the NADIN IA concentrators for end user connectivity. The non-NADIN IA users of NADIN II, mostly central information dissemination systems, will benefit from the perspective that once they access NADIN II directly they will have connectivity to all NADIN IA users. More succinctly put, a parallel NADIN IA will not expedite their access to NADIN II, but will expedite their connectivity to end users once they access NADIN II.

The ability to use HCAP to access AT&T T1 links and connect nodes prior to RCL completion is another facet of the design that aids in a smooth implementation period.

Enough cannot be said about the wisdom of choosing system characteristics that adhere to industry standards. The expandability such design provides is essential in today's technological environment. Cost savings associated with buying commercial of the shelf (COTS) components is tremendous and COTS components lend themselves well to adherence to the industry standards mentioned above. The Department of Defense could learn a valuable lesson by watching the outcome of current FAA telecommunication design efforts.

E. COST CONSIDERATIONS

Costs are a major consideration in system design. The FAA obligates itself to meet service demands and must do so within fiscal constraints. Optimizing the service provided for the dollar is a complex objective. The FAA realizes that it must take a long term approach to capital investment projects like NADIN II. The only sensible way to analyze the costs of a system like NADIN is over an extended time period.

In the case of NADIN two major cost areas exist, non-recurring costs and recurring costs. Non-recurring costs are typically capital investment expenditures for equipment and project implementation. Recurring costs are primarily leased line costs but include other operating costs as well. It is difficult to analyze costs of NADIN II while treating it as a single entity. As discussed in Chapter V, NADIN II is one of several FAA programs that comprise the backbone network in a telecommunications sense. System cost considerations are more relevant when viewed from a total network perspective. NADIN II costs are significantly affected by associated leased line costs in future years of operation. The FAA is currently spending 190 million dollars annually for all leased communication services agency-wide. Table 5 lists leased line cost savings and avoidance attributed to projects associated with the backbone network for interfacility communications. [Ref. 1:p. xi] The values in Table 5 are the dollar values of leased line costs that were avoided by use of FAA owned

equipment. By fiscal year 1996, leased communications cost savings and avoidances reach 144,098,000 dollars annually and are expected to increase in future years. Note that the asset category labeled Purchase consists of various FAA-purchased equipment, such as integrated communication switching devices, modems and multiplexors. Initial capital outlays result in negative cost avoidances for years 1990 and 1991 but contribute considerably to cost savings in subsequent years.

Table 5. LEASED LINE COST SAVINGS/AVOIDANCE

ESTIMATED LEASED COMMUNICATIONS COST SAVINGS/AVOIDANCE						
ASSET	FY90	FY91	FY9●	FY93	FY94	FY96
DMN	1174	12274	30119	39900	44595	48205
RCL	4	1307	10953	32146	46277	50920
NADIN 1A	116	116	140	152	369	1026
NADIN II	0	0	2642	6283	6589	7196
PURCHASES	-2363	-9687	25151	11839	15004	36751
TOTAL SAVINGS	-1069	4010	69005	90320	112834	144098
Values are in thousands of dollars.						

Future costs associated with NADIN II are shown in Table 6 [Ref. 1:p. 35-12]. Non-recurring costs diminish rapidly as capital investment expenditures become complete. Recurring costs rise as network links reach completion and total leased line costs increase. But in fiscal year 1993 leased lines begin to be replaced with RCL links and recurring costs drop until all links are carried by RCL.

Table 6. NADIN II COSTS

NADIN II COSTS (in $1,000's)					
COSTS	FY92	FY93	FY94	FY95	FY96
Nonrecurring Costs	670	433	272	0	0
Recurring Costs	1630	4078	2816	737	737
Total Costs	2300	4511	3088	737	737

Comparison of NADIN II costs and leased line savings attributed to NADIN II reveals a project that should more than pay for itself in several years. Costs associated with RCL, DMN and other projects that comprise the telecommunication network based around NADIN II that can be attributed to NADIN II are difficult to discern from those total project costs. It is not FAA procedure to delineate costs in this manner, so here the analysis reverts back to just NADIN II project costs versus NADIN II associated lease line savings. Suffice it to say that the other projects fare just as well under this type of analysis and pay for themselves in similar time periods.

The NADIN II project recovers costs in just several years via leased line savings and the benefits to the FAA and the aviation industry have not been tolled yet. This benefit is difficult to quantify, but at this point it should be sufficient to say that some portion of the estimated total benefit of FAA projects, shown in Figure 12, is attributed to NADIN II.

F. NADIN CAPACITY

The two major demand forces impacting NADIN are aviation industry growth and expanding FAA services that will use the network. As discussed in Section B, FAA workload measures are expected to increase 2.4 percent annually due to aviation industry growth. At this rate the workload measure will be 26.8 percent greater in 2002 than in 1992.

Non-NADIN IA services that plan to use NADIN II and are currently operating demand very little capacity relative to the NADIN IA air traffic control (ATC) functions. Future services slated to use NADIN II are difficult to quantify as many are still being designed or implemented. Most of these are central information disseminators and do not require as much network capacity as operational ATC services. Since demand on NADIN II from these non-NADIN IA users is practically impossible to quantify, a heuristic approach will be taken. Will total NADIN capacity be reasonably large enough to provide positive expectation of sufficiency?

The NADIN II project provides a data rate capacity of 56 Kbps per link while still retaining NADIN IA's 9600 bps links. The NADIN II project not only increases link capacity six fold, but a more interconnected topology increases the quantity of data that can be handled by the network. Routing flexibility of the packet switched network makes efficient use of the links and will again multiply the capacity of the

network. Reliability also increases with multiple routing paths.

Certainly the 26.8 percent aviation growth over the next ten years will be easily handled by the large network capacity increases provided by NADIN II. Demands from new users remain unknown, but network capacity should handle extensive expansion of NADIN use.

G. IMPLEMENTATION PROBLEMS

As of May 8, 1991, 26.2 million dollars had been committed by the NADIN II project. 52.2 million dollars was the total funding approved. The program manager estimated 76.3 million dollars in total would be required by completion.[Ref. 8] Cost overruns exist because of inadequate original estimates and incomplete requirements or specifications [Ref. 12:p. 8].

The FAA has committed several errors regarding contracting. These errors have been typical in government agencies, most notably the Department of Defense. Being a commercial off the shelf design and paving no new paths in technology, the FAA felt a firm fixed price contract was well suited. In typical fashion, the company that was awarded the contract, Harris Corporation, had underestimated costs, and the FAA had done an inadequate job of specifying technical requirements. This left Harris Corporation looking for contract loopholes to reduce their costs and resulted in various disputes concerning interpretation of technical

requirements in the contract. Portions of the contract were renegotiated and settled at increased cost to the FAA.

Harris Corporation did not have adequate personnel resources for the development and implementation of the NADIN II test program. This caused delays early on and the current plan of action requires Harris to acquire more test engineers and managers.

A delay in implementation of NADIN II due to funding problems or contractor failure to meet schedule requirements, will have far reaching effects in the FAA. Many other systems are depending on NADIN II to provide connectivity. The NADIN II program manager stated last March:

> Full funding of the National Airspace Data Interchange Network (NADIN) II is required if NAS communications objectives are to be achieved. Any delay or failure to implement NADIN II will have severe implications including: delays in achieving required communications availability and diversity, delays in achieving communications cost reductions through optimization of shared network facilities, and delays in achieving desired data communications system flexibility. [Ref. 12:p. 9]

Conversely the delay of other programs may hinder the NADIN II program. Specifically the Radio Communication Link (RCL) program may run into some delays providing FAA owned microwave links to NADIN II. AT&T was contracted to upgrade existing components on FAA microwave towers. Fifty two of these towers proved to be faulty and required unexpected replacement prior to the AT&T installation of upgraded telecommunication components. [Ref. 7] The resulting delay may affect NADIN II implementation.

VII CONCLUSIONS AND RECOMMENDATIONS

The National Airspace Data Interchange Network will successfully accomplish its objectives and contribute to overall FAA mission success. The utilization of technology and system design that allows for flexibility and interoperability of the system will ensure that NADIN is able to continue to meet demands placed on it well into the 21st century.

The capacity expansion that NADIN II provides to NADIN is more than sufficient for today's demands and future forecasted demands. The link capacities were selected from a menu of available technologies, at a level that assures adequate capacity, rather than through meticulous network analysis. This breaks from the FAA track record of creating its own system to its own standards. NADIN will benefit greatly from this enlightened approach of adhering to industry standards.

The NADIN program manager is committed to the current contractor, but should remember the contracting lessons learned. Future programs should place more effort on specification development. Contractor selection should avoid the low bid mentality and ensure the contract awardee has sufficient resource capacity and expertise to meet schedule, cost, and quality goals. The contracting shortcomings of the

NADIN II program will hinder schedule and cost objectives but will not impair the program.

Cost overrun is a significant issue for the NADIN II program manager, currently, and in the immediate future. Fortunately the program is on extremely sound ground from an economic point of view. The tremendous leased line savings rapidly offset implementation costs. If this program were a private industry endeavor, fiscal support would be very strong. However it is a government program. Often those who determine program funding do not have a long range perspective. Even though the program is very cost effective over a relatively short number of years, it still requires cash outlays today. These dollars are today's tax dollars and come from today's budget. Future cost savings and avoidance are not cash inflows and are difficult for fiscal decision makers to appreciate. The program manager must ensure that fiscal decision makers have a clear understanding of the economic soundness of NADIN II, and she must fiercely pursue the necessary funding required to implement NADIN II on time. Program support will not come due to the merits of the program alone. The program must be sold continually to ensure complete fiscal support.

One method by which the FAA could enhance their ability to demonstrate the economic merits of their programs is to provide literature with a less segmented systems approach. As discussed in Chapter I, the FAA segments interactive programs

mostly for accounting purposes. This obscures many merits of individual systems as they fit into the broader system. Fiscal decision makers are not usually technical experts on all the areas for which they determine funding. Thus they cannot always see the value of what they are being asked to fund. The FAA should provide documentation geared to provide the layman with a total system overview.

The consolidation of systems and reuse of existing assets with technological upgrades, like the RCL or continued NADIN IA concentrator use, provides tremendous economic leverage and should be continued in future system designs.

The aviation industry and all FAA service users will see enhanced services provided at high quality standards in the coming years. NADIN will be a significant part of that effort and the NADIN II program will prove to be quite a success.

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